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DRY PORTS IN SWEDEN - ONE OF A KIND?

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Abstract: *Swedish dry ports have been often used as cases in the transport research, however there is no comprehensive study that identifies and categorizes Swedish freight transport terminal facilities meeting the dry port definition "inland intermodal terminal with direct rail connection to a seaport where customers can deliver/collect their containers as if directly at the seaport". This study aims to describe those facilities and to analyze them focusing on several distinctive characteristic identified from the literature on dry port. The study used primary and secondary sources of data. The findings show description and analysis of identified dry ports in Sweden: not only the number of them grew from two in the year 2009 to 12 in the year 2022, there are similarities but also differences when it comes to their distance and location, functionality and services, direction of development, maturity level, dedication, geography of operations. One characteristic they all have in common is Inside-out directional development.*

Keywords*: Dry port, intermodal terminal, services, Sweden*

1. INTRODUCTION

One of the roles of dry ports is to serve the seaports to release the pressure of growing cargo volumes and to reduce CO_2 emissions by modal shift from road to rail. Dry ports are commonly described in the literature as important nodes of inland transportation system benefiting multiple actors of the system from different perspectives. One of the benefits is for the regions located in the hinterland of the seaports where dry ports are implemented so that the availability of dry ports with the services offered attracts new business and investments in the area (Božičević et al., 2021). Previous research on dry ports has been focusing on different thematic areas usually based on cases of dry ports, often from different geographic regions, that are sometimes difficult to justify as comparable (Khaslavslaya and Roso, 2020). Such research instances help to rather underline differences than the similarities. However, there are country-specific studies and even a global perspective on dry ports such as e.g. Monios and Wilmsmeier (2012), where the authors make conclusions from several cases from across Europe and the USA and point out the different strategies of ports and authorities regarding hinterland infrastructure development. Swedish dry ports appear frequently in the research; one of

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the studies with the similar focus identified only 2 dry ports in Sweden in 2009 (Roso, 2009). Since then, many things have changed in the transportation system in Sweden, and the number of dry ports grew significantly. Therefore, the purpose of this study is to qualitatively describe the facilities identified as dry ports and analyze them focusing on significant characteristics identified from the summary of the relevant literature. The contribution of the paper lies in the analysis of all dry ports in Sweden with respect to their distance and location, functionality and services, direction of development, maturity level, dedication, geography of operations, the paper provides an updated detailed description and qualitative analysis of the dry ports in Sweden.

This introduction of the paper is followed by overview of dry port literature and Swedish transport system. Method chapter concisely describes the research approach applied. Findings are presented in the chapter four where all identified dry ports in Sweden are briefly described. This is followed by analysis and discussion and finally, the paper conclusions are presented in the chapter six.

2. DRY PORT CONCEPT AND SWEDISH PERSPECTIVE

Dry port concept emerged due to increasing need for efficient intermodal transportation in the seaports' hinterland (Wilmsmeier et al., 2011, Roso et al., 2009). On one hand, seaports have been facing capacity issues due to rising volumes of international trade as well as the increasing sizes of the vessels calling to the seaports. On the other hand, the landlocked regions have been seeking development opportunities and have been developing intermodal infrastructure to facilitate access to the seaports and their transportation network. Together, it led to development of a dry port concept (Wilmsmeier et al., 2011), defined as an inland intermodal terminal directly connected to a seaport by rail, where customers can leave/pick up their standardized units, as if directly at the seaport (Roso et al., 2009). The main idea behind the concept is to serve as the seaport interface inland which implies a presence of infrastructure that allows efficient transport of consolidated containerized cargo as well as frequent, scheduled, and reliable high-capacity transportation (ibid). Often the research on dry ports highlights the availability of rail infrastructure and rail shuttles as an element of dry port concept e.g. Bergqvist and Woxenius (2007), Chang et al. (2018), Rodrigue and Notteboom (2012), Roso (2008), and Roso and Russell (2018). Furthermore, dry port being a seaport's interface inland implies that the shippers/customers have an opportunity to handle their cargo at a dry port in the same way as if they would do it in a seaport i.e. that the services typical to a seaport are expected to be available at the dry port (Roso et al., 2009, Khaslavskaya et al., 2021). Dry port concept has a positive effect on sustainability components. Firstly, cost-efficient hinterland transportation by high-capacity transport modes (rail, inland waterways) compared to business-as-usual alternatives (road) could bring economic benefits to the whole supply chain (Khaslavskaya and Roso, 2019). Secondly, intermodal setup (hinterland transportation through a dry port) has lower environmental impact (especially if the rail is electrified) (Khaslavskaya and Roso, 2019, Henttu and Hilmola, 2011, Roso, 2007).

Finally, development of dry ports could stimulate regional development since availability of functional logistics solutions attracts new businesses to the area, which results in new job opportunities (Roso, 2009). The research on dry ports branched out in multiple focus areas; among others, several scholars focused on identifying unique significant characteristics of dry ports that distinguish them from other inland terminals and classifying them. The summary of these is adapted from Khaslavskaya and Roso (2020), see the table 1.

Sweden has been used as a case in many research papers focusing on dry ports; and the researchers have focused on various aspects, starting with concept development (Roso et al., 2009) to much more specific aspects e.g. evaluating of the concept from an environmental perspective (Roso et al., 2009, Henttu and Hilmola, 2011, Roso, 2007), dry ports directional development (Bask et al., 2014), a potential of dry ports in Sweden to mitigate supply-chain disturbances on the example of a labor conflict (Gonzalez-Aregall and Bergqvist, 2019), role of dry ports in supply chains (Khaslavskaya and Roso, 2019). All the aspects risen in the research include several actors that influence operations and sustainability of the implemented concept. Those actors have been contributing to sustainable development of inland freight transportation (Monios and Bergqvist, 2016, Dooms, 2019) such as e.g. government authorities have required greener transportation.

Table 1. Dry port characteristics identified in literature

Criteria	Dry port types	Authors
Location and function	Close, midrange, distant Seaport-based, city-based, border	Roso et al. (2009) Beresford et al. (2012)
Development direction	Outside-in, Inside-out; Bidirectional Land-driven, sea-driven	Wilmsmeier et al. (2011) Bask et al. (2014) Monios (2011)
Maturity level	Pre-, start-up, growth phase	Bask et al. (2014)
Dedication	Shared (public), dedicated to an enterprise or cargo	Ng and Cetin (2012)
Geography of operation	Domestic, international	Do et al. (2011)
Transport mode	Rail-based, barge-based	Rodrigue and Notteboom (2012)
Service portfolio	Basic services; basic and value-added services; basic, value-added and customized services	Khaslavskaya et al. (2021)

The Port of Gothenburg, together with other major business actors, tried to significantly reduce carbon emission associated with its business by 70% by 2030. So-called "The Tranzero initiative" concerns electrification of large trucks and sea transport (Tranzero, n.d.). Earlier, the port has also been focusing on efficient hinterland transportation network under the "Railport Scandinavia" initiative, which implies electrification of rail lines and promotes a network of hinterland terminals connecting the hinterland with the port [25]. In addition, regions in their development strategies have been driving infrastructure construction to reach out to the seaport and their established international transportation network (Khaslavskaya and Roso, 2019, Bergqvist and Monios, 2021).

3. METHOD

The data for this study has been collected from primary and secondary sources; by interviewing representatives of the dry ports and other actors related to their business but also from available reports/literature. In addition, student reports about intermodal terminals in Sweden from the course Freight Transport Systems thought at Chalmers University of Technology in the fall 2021 were used as an extra source of data. For each dry port a document with a summary was written, which also included a list of open questions when desired data was missing. The summaries were sent to the dry ports with the request for verification. In most cases the verification was handled vie e-mail correspondence, in few cases there were additional phone and Teams calls. Descriptive analysis has been applied on the data collected. Finally, identified and analyzed dry ports have been compared based on the criteria previously recognized and mentioned above.

The initial list of inland intermodal freight terminals was collected from sources of the Port of Gothenburg, which is promoting hinterland network of so-called Railports. The list was taken as a basis and then assessed together to the experts and limited to those that fit into the definition of dry port. The main criteria to include an inland intermodal freight terminal in the final list for the further research steps was an established regular train connection to/from a seaport (i.e. existing volumes to handle) and extra services available at the facility.

4. SWEDISH INLAND INTERMODAL TERMINALS IDENTIFIED AS DRY PORTS

This chapter briefly describes all identified dry ports in Sweden that are shown on the map in Figure 1.

Eskilstuna Intermodal Terminal is fully owned by the municipality through Eskilstuna Logistik och Etablering AB which initiated the development of the terminal which is a part of the logistics center. The terminal has rail connection to seaports by Green Cargo, GDL and TX-Logistics. It was established in 2003, first it was operated and managed by Green Cargo, since 2004 the daily operations at the terminal are performed by M4 with their own equipment and personnel – a consortium owned by 270 different transport and construction equipment companies from the Mälardalen region. The biggest customers are H&M, BSH Home Appliances, ICA, Volvo and Coop.

Jönköping Kombiterminal AB was inaugurated in December 2010. The land is owned by the real estate company Catena and the terminal itself is initiated and owned by the Municipality of Jönköping. The operations are managed by Bring Linehaul AB that is responsible for all the services available at the terminal. The largest customers are IKEA and Elgiganten, while there are some smaller companies also using the service of transporting their goods by train between Torsvik and Årsta, Stockholm.

Figure 1. Dry ports in Sweden

Umeå terminal was initiated due to Bothnia Line – rail link connecting the north and the south of Sweden – which was introduced in 2010. The terminal is also connected to Stambanan that allows access to the entire railway network of Sweden. Most inbound goods are transported by train from terminals located in Göteborg, Malmö, Helsingborg and Nässjö. Umeå Combi terminal is established and owned by Trafikverket and then leased to Infrastruktur i Umeå AB (INAB). INAB in turn has hired Sandahls Goods & Parcel (a private company) to handle the daily operations. The main customers are Volvo, IKEA, Biltema and Carlsberg.

Hallsberg Terminal was built in 2003, actors that were involved in the implementation were the Hallsberg municipality, Rail combi, Green Cargo and Euroshuttel. Logent AB took over the operation of the company in 2012 and started to run rail shuttle to the port of Gothenburg. The terminal is now owned by Catena AB a real estate company and has around 40 different customers. The terminal is directly connected to the Nordic region's largest marshaling yard is within a radius of 20 miles to over 50% of the country's population and over 60% of businesses.

Vaggeryds terminal was initiated in 2009 by PGF Terminal AB and they started the rail shuttle to and from the Port of Gothenburg. It began with signing an agreement between a paper company, municipality, and themselves to test the concept of a dry port. By April 2010 the terminal was ready, and the first containers arrived. Initially the terminal competitiveness was low due to risks of missing a time slot and thus delaying goods. However, the industry was interested and over time the terminal gained competitive advantage and reduced risks of delays. Now the terminal is owned by the municipality of Vaggeryd and is leased and operated by PGF Terminal AB, a part of the PGF Group.

Katrineholms Logistikcentrum is a development area of 1 000 000 square meters of land for the establishment of logistic operations. The site is strategically placed in the crossing of two of Sweden's main rail lines, the West and the South mainline. Its position also reaches a third of Sweden’s population within a 15 miles radius. The terminal has been operating partly since 2010 and fully since 2011. The terminal initially was owned by the municipality, however, after obtaining municipal shares GDL became the major owner. The terminal has only one customer, that is GDL and they manage the operations to their own customers like e.g. Amazon Web Services, Bosab, Catena, Postnord AB.

Stockholm Årsta Kombiterminal is located six km from the Stockholm city center and serves more than three million customers through rail and road combined. It is Årsta Kombiterminal is owned by Jernhusen AB, and is since January 2017 operated by Väte Trafik. The implementation of the terminal was initiated by Jernhusen since they wanted to increase the value by developing the properties and the terminal. Jernhusen was also the main investor of the implementation. Green Cargo is the main rail operator, the terminal itself does not work with goods’ owners, only with the operator.

Kombiterminal Gammelstad (Luleå) was inaugurated in 2003 and is owned by the Luleå municipality that together with Swedish transport administration works on the development of the terminal. The municipality owns the ground and the Swedish transport administration owns the tracks. The operator of the terminal is Sundahls Goods & Parcel AB. Main customers are Polarbröd and Scania, but also the forest industry and other companies established in Västerbotten and Norrbotten.

Sundsvall Combi Terminal, the existing combi terminal in operation is located centrally and is operating at the of the maximum capacity and the opportunity to expand is strongly limited due to vicinity of residential area. Existing flow of goods consist of a large proportion of hazardous goods that create heavy traffic through the city center. Therefore, new combi terminal is planned to be completed in 2024, location is north of the city close to the Tunadals port and with connection to the rail network. The process of building this new terminal begun in 2008 when the municipally of Sundsvall created the company Sundsvall Logistikpark AB and in year 2011 the zoning plan was adopted by the City Council. Sundsvall combi terminal works with many customers such as DSV, DHL, Noyroun, IKEA and Biltema.

Dry Port Falköping – Skaraborg Logistic Center was initiated by Falköping municipality in 2000. The terminal has a close collaboration with the Port of Gothenburg and has gone through a big improvement and expansion during the last years. The terminal started with operations in 2007 but had issues with volumes handled until Jula AB started to use the terminal in 2013. After contracting Schenker AB, Jula AB purchased the terminal from the municipality in 2018 and started to work on attracting more volumes to the terminal. Jula logistics is now the Owner and operator of the dry port. Transports are contracted to Schenker who are responsible for the transport by truck and Tågfrakt who are responsible for the trains. Even though the ownership transferred from the municipality to Jula there is still a close collaboration between the actors in the future plans of the dry port.

Insjön Kombiterminal is located in Leksand municipality which plays an important role for the large companies such as Clas Ohlson, Bergkvist Siljan AB, Tomokuhus and Ejendals. The development of the dry port was initiated in 2002, when Bergkvist-Insjön AB wanted to secure their export of timber products to Asia. The terminal is operated by Vänerexpressen that connects the port of Gävle and the port of Gothenburg.

5. ANALYSIS AND DISCUSSION

5.1 Distance and location

According to Roso et al. (2009), dry ports functionality to some extent correlates with their location (or distance) in respect to the seaport that they serve; close, mid-range and distant. Another way to classify dry ports based on location/distance is to distinguish seaport-based, city-based, border-based dry ports (Beresford et al., 2012). In this study in the respect of location and function the dry ports were analyzed based on their functionality and distance from the port of Gothenburg. The distance from the Port of Gothenburg by rail is taken from the port's report, while the road distances are taken from the Google maps and the same are shown in Figure 2. Only three dry ports are located very far, more than 800km and those clearly benefit from use of rail. Five are on "medium" distance of 200-600 km away from the port and three are closer than 200 km to the port and therefore feasible for use of road but volumes and frequencies make the rail viable. The dry port in Nässjö is located 230 km away by rail while just 190 km by road and thus can be classified in different ways; it is classified to be close-range one in this paper which is closely related to its functionality discussed in the next chapter.

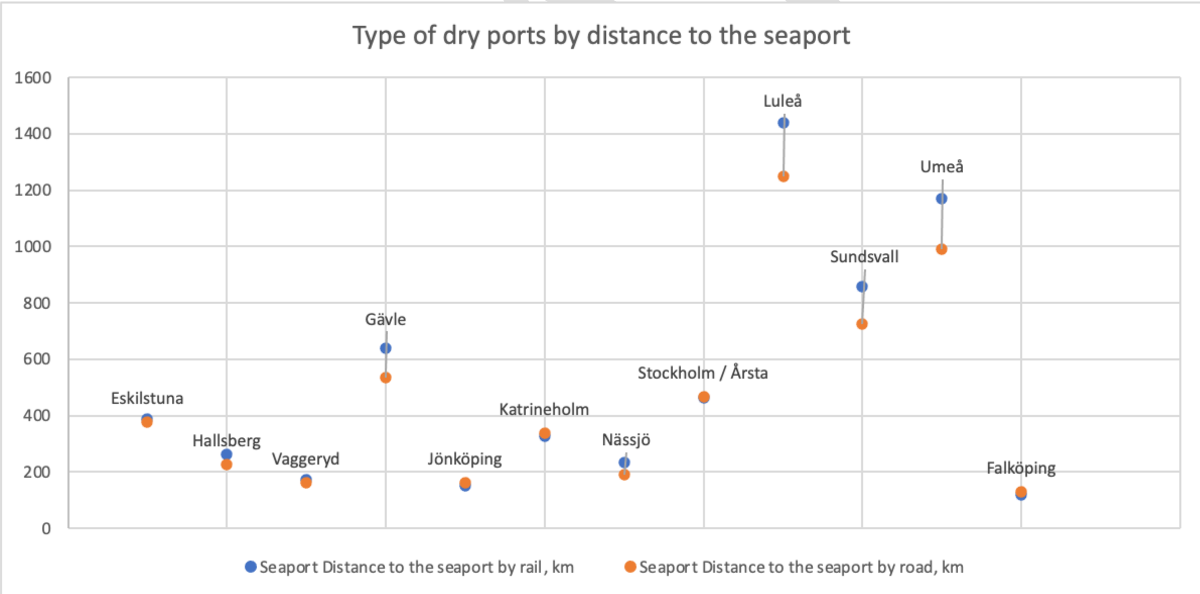

Figure 2. Distances to the seaport

5.2 Functionality and services

As per available services, the dry ports in Sweden have quite similar service portfolio which always consists of basic services and different set of value-added and customized ones. While if demanded, the dry ports are ready to add a requested service even if the volumes are not very significant and there is a competition between the dry ports especially located in relative proximity to each other. The most frequent services at dry ports are depot, handling of dangerous goods, reefer plugs, stuffing, transhipment, handling of empty and loaded containers, road haulage. Less frequent services are container consolidation, online booking, safe parking for trucks / trailers, customs clearance, forwarding, warehousing, tracking and tracing, material control, subassembly, kitting and sequencing cross-docking, repacking and relabeling, quarantine, quality and inventory control, and repair. It is challenging to count exact frequency of services because some of them are available by request but not listed online.

Figure 3 shows services importance evaluated by stakeholders (transport operators, municipality, shippers, seaport). The importance is evaluated from 0 (not important) to 5 (very important), the graph allows to see the important per each stakeholder as well as it indicates the common perception of the importance per each service.

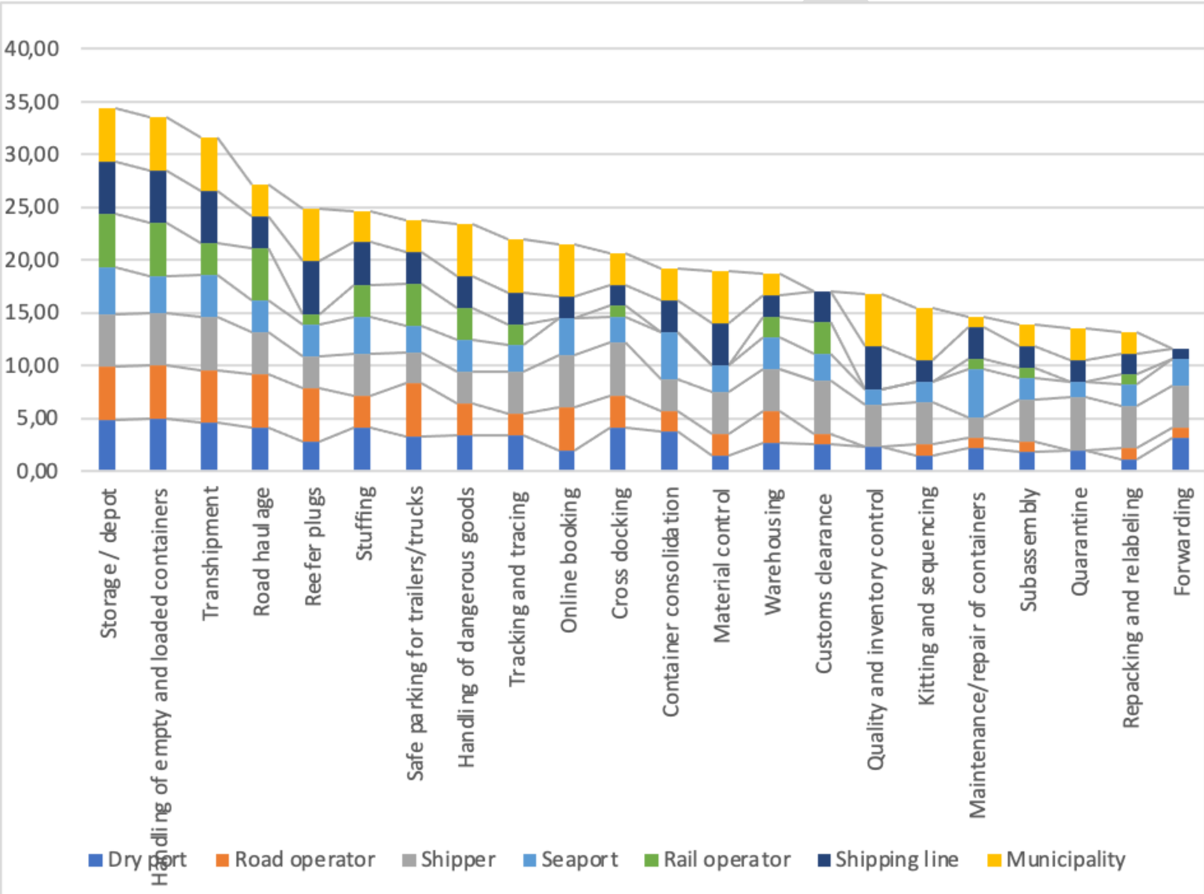

Figure 3. Dry ports services' importance according to the stakeholders

5.3 Directional development

Dry ports in Sweden are initiated by a several stakeholders located in the hinterland. The roles of actors change over the time together with the development of terminals. The findings show that all dry ports included in this study have followed the Inside-out model of the development, that means that the initiation of dry ports development came from actors located in the hinterland. Moreover, there has mostly been a common interest of the municipality to develop the region and at least of one large shipper with sufficient for a regular train volume. For example, The Eskilstuna Intermodal Terminal was initiated by the municipality when H&M in 2002 moved distribution center to the area. While the development was possible due to initiative or a great support from municipality, the initial investments were financed jointly by municipalities, large shippers and in some cases by external grants aiming to support low emitting transportation solutions. For example, half of the finances for the dry port development in Luleå came from the Swedish Agency for Economic and Regional Growth. Vaggeryd dry port investments were financed by the municipality, EU grants, Traffikvärket and many other smaller investors. Sundsvall Combi Terminal obtained the investment from the Swedish Transport Administration, Svenska Cellulosa AB (SCA) and the county administrative board.

The role of the municipality in dry ports development steadily decreases as the terminal moves further along the developmental phases. It has been noted, a start-up stage of dry ports development (Bask et al., 2014) has always involved a respective municipality, on the later stages the municipality may have retreat in order to hand it over to the private actors. It has happened with Katrineholms Logistikcentrum where GDL became the owner of the terminal after obtaining municipal shares; Dry Port Falköping was purchased from the municipality by a large retailer company Jula AB who started to operate the terminal, obtained own rolling stock as well as established close cooperation with the rail operator Schenker AB. This being an exceptional case in Sweden, is also a case of success of a dry port operations. In Vaggeryd the terminal is leased and operated by PGF Terminal AB; in Umeå while Trafikverket (public authority) owns the facility, it is operated by Sandahls Goods & Parcel AB; M4 rents the terminal from the Eskilstuna municipality and owns machines and has own employees.

Interesting, that while the role of the Port of Gothenburg in the initiation and development of any dry ports in Sweden is minimal, the port is nevertheless promoting its “Railport Scandinavia” concept that encompasses all the possible dry ports and established rail network connecting to all of them. During interviews with other sea container terminals in Sweden it became evident, that the other seaports are not agreeing with such position. From the findings, a dry port in Sweden is a terminal with an established rail traffic. In line with this, there is another viewpoint that seaports as operators do not conduct such activities as hinterland distribution, while in fact the dry ports are part of the traffic arrangements that the railway operators offer to the market on equal terms. It became evident, that the biggest port enjoys its competitive advantage and perhaps to some extent does not let others into the business that it does not directly possess. It echoes the conclusions by Monios and Wilmsmeier (2012), where the authors point out only an assisting role of seaports in dry ports development. Similarly, Bask et al. (2014) pointed that the seaports’ role not going beyond marketing of the dry port concept with the impalpable/unmeasurable positive effect on cargo flows and service demand at the dry ports.

5.4 Maturity level

In some cases we could observe similar patterns to the ones identified by Bask et al. (2014), that of the terminals are often initiated by an inland actor (municipality or an entrepreneur-minded person or a group of people and by joining the effort and obtaining (often municipal or private funds) the terminal is built constructed. For the current moment, there were no identified cases of a start-up phase of constructing a brand-new terminal, all the identified ones have passed the phase. It is fair to say that most terminals are in the growth phase which is recognized by operations and infrastructure development and capacity utilization of about 20-60% (where known). Many dry ports in Sweden have plans of extending the territory, operational areas, tracks, some of them have recently completed the same extension. There is also an interesting case which is not simple to classify in the same terms – the dry port in Sundsvall – which in a way is undergoing a rebirth, or a metamorphose. The old intermodal terminal in Sundsvall was built about 50 years ago and has been operating on the maximum of its capacity; for the moment of this study there was an ongoing project of building a brand-new terminal to be completed by 2024 which would substitute the old one in its function. Somewhat similar phenomenon was observed in the case of Vaggeryd, where prior to the terminal construction operations with minimal needed investments were conducted at the old terminal adjusted for the needs of a dry port. After it had proved to be feasible the actual dry port terminal was constructed. While the cases are not identical, they have a similarity in their "metamorphosis".

5.5 Dedication

Officially dry ports are not dedicated to any enterprise in Sweden regardless of ownership: by a municipality or a private company. Most of them have contract with rail transport operators, not directly with the cargo owners. Most of the dry ports, however, poses information about the largest cargo owners and can name a few such as IKEA, Volvo, Elgiganten. Despite not being dedicated to a single shipper, trains between Jönköping and Gothenburg are popularly called "IKEA-pendeln (commuter train)" and between Falköping and Gothenburg – "Jula-pendeln" (commuter train). It does not mean that they transport goods only of those companies, but they do mainly. Interestingly, after the acquisition of the dry port by Jula AB in Falköping, the new owner would allow the containers of other companies to the train prior to their own to establish trustful and reliable relationships with new clients in new business area. It is out of authors' knowledge whether this is still the case of today.

5.6 Geography of operations

As it was previously mentioned, dry ports enjoy the benefits of the established rail network of Swedish rail operators such as Green Cargo AB, GDL, Real Rail, Schenker AB, Vänerexpressen AB. All the dry ports have rail traffic to/from the port of Gothenburg, some of them work with the cargo originating from/destined to other container seaports of Sweden i.e. Mälmö, Trelleborg, Stockholm, Gävle, Helsingborg. There are international trains going to/from Germany, Biebersheim. There is always a hard work involved in assuring the backload of the trains, detailed information was not possible to obtain, however, there was indication that a backload of 65% can be sometimes stably assured and meets the expectations of the dry ports. The backload is easier to provide with the trailers and sometimes reaches up to 100% in those cases.

6. CONCLUSION

According to the purpose of this study, detailed qualitative descriptive data about the dry ports in Sweden were collected and analyzed with focus on distance and location, functionality and services, direction of development, maturity level, dedication and geography of operations. The results of the analysis indicate that the dry ports in Sweden are homogeneous in many respects. All the dry ports in Sweden are initiated by the actors in hinterland and thus are initially constructed to meet the goals of municipalities and local businesses; and as such fit into Inside-out directional development model. Majority of the dry ports are “mid-ranged” that means that they are located 200-600 km from the Port of Gothenburg; yet there are close and distant dry ports as well. To defiantly state the dependance of the service offerings and location further study is needed, however, it is evident that there are frequent services at dry ports all around the country including depot, handling of dangerous goods, reefer plugs, stuffing, transshipment, handling of empty and loaded containers, road haulage. As per development, there were no identified cases of a start-up phase, most of the identified dry ports are in the growth phase which is recognized by operations and infrastructure development and capacity utilization of about 20-60% (where known). The analysis of the involvement of actors through the developmental phases highlights minor role of a seaport in the beginning which increases along the maturity of the dry port (from establishment to operations). Privately initiated and owned dry ports may pursue otherwise not common strategies such as close collaboration and integration of business with large shippers or rail operator. Further research is needed to confidently state whether the dry ports in Sweden compete, are in co-opetition with each other, or cooperate, however, it is evident that they depend on the same established rail network and enjoy its benefits in terms of geographical coverage and reach to the seaport terminals. One of the major issues is unbalanced flow of containers which is addressed by the dry ports to different degrees. The conducted data analysis contributes to the dry ports concept by elaborating on pre-existing classifications of dry ports, discussing the classifications with regards to the case of dry ports in Sweden.

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LOCATING A HUMANITARIAN LOGISTIC CENTER: CASE OF SERBIA

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Abstract: *Nowadays life is becoming unpredictable regarding nature control and potential ecological problems. In situations when a natural disaster overpowers the human mechanism of defense, readiness for a fast reaction is the key. An extremely influential alleviation factor of disaster consequences is an adequate realization of logistic activities which in large depends on the location of the humanitarian logistic center. This task has strategic proportions and represents a potential issue while providing first aid to threatened parts if the solution is not optimal. Locating the humanitarian logistic center is a complex issue and involves considering various alternatives and criteria for its valuation, therefore multi-criteria decision-making methods are used. In this paper, the location of the humanitarian logistic center in Serbia has been considered on the territory of Novi Sad, Belgrade, Kragujevac, and Niš. Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method is used for problem-solving. By processing the data and comparing alternatives according to the relevant criteria, Belgrade has been determined as the optimal location of the humanitarian logistic center for the case of Serbia.*

Keywords*: humanitarian logistics, logistics center location, multi-criteria decision-making, PROMETHEE.*

1. INTRODUCTION

Logistics is present in all economic and social activities, but it is also an integral part of everyday life. Increased interest in logistics and its application has led to a myriad of definitions and different interpretations of the concept of logistics. Most definitions of logistics include that it is the process of planning, designing, modeling, projecting, controlling, and managing processes and systems that enable the flow of materials, products, energy, information, people, and money (Kilibarda, 2012). In short, logistics include all systems and processes which enable material and non-material flows (Zečević,

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2006). In logistics, the main goal is to provide required goods on the market at the right time, at the right place, in the right quantity, with the highest level of service, and at the lowest possible cost using the available resources and human resources. Thus, logistics is a particularly important function in emergencies, where it is necessary to quickly provide aid to the vulnerable and provide goods to prevent and mitigate the consequences.

In 2021, the Center for Research on the Epidemiology of Disasters (CRED) reported 432 catastrophes related to natural hazards worldwide (EM-DAT, 2022). There were 10,492 deaths, 101.8 million people were affected, and about $252.1 billion in economic losses. Compared with the average of 357 catastrophes per year, for the period 2001-2020, the number of recorded catastrophic events in 2021 is considerably higher. Floods dominated these events, with 223 occurrences in comparison to an average of 163 per year during the period 2001-2020. The number and impact of natural and man-made disasters worldwide have significantly increased in the past decade, showing a growing trend. Humanitarian logistics should suppress the effects of natural disasters, as well as problems caused by human factors. A well-organized and efficient logistical support system is essential when providing assistance in emergencies or after disasters. The effectiveness of humanitarian aid largely depends on humanitarian logistics. Locating the Humanitarian Logistics Center (HLC) stands out as one of the significant factors in achieving the efficiency of humanitarian logistics.

This paper aims to emphasize the importance of appropriately locating the humanitarian logistics center for the territory of Serbia and defining the methodology for that procedure. After described characteristics of humanitarian logistics and the significance of HLC locating, a description of the multi-criteria decision-making method PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) is given in chapter 2, and it is used for the selection of location for the humanitarian logistic center. In chapter 4, criteria are evaluated and the multi-criteria issue of HLC location selection for the territory of Serbia is resolved. At the end of the paper, final conclusions and possible directions for future research are given.

2. HUMANITARIAN LOGISTICS - BACKGROUND OF THE PROBLEM

Logistics is defined as the part of the supply chain process that deals with the planning, implementation and control of efficient and effective flow and storage of goods, services and information, from the point of origin to the point of consumption, to meet customer needs (Council of Logistics Management, 1998). Humanitarian logistics is a special area of logistics whose main goal is to provide aid to people in need during emergencies or natural disasters and to prevent or mitigate their consequences. Although there are many interpretations of the term humanitarian action, three widely accepted principles - humanity, neutrality and impartiality - must be present for an action to be considered humanitarian (Tomasini and Van Wassenhove, 2009). The principle of humanity indicates that human suffering should be resolved wherever it is encountered. According to the principle of neutrality, assistance should be given without bias or belonging to a particular party to the conflict, while the principle of impartiality indicates that assistance should be given without discrimination, with priority being given to those in greatest need. The term humanitarian logistics refers to the planning, implementation and control of efficient and economical movement and storage of goods, materials, and information from the place of origin to the place of consumption, in order to alleviate the suffering of vulnerable people (Tomas and Kopczak, 2005).

There is a natural disaster in some parts of the world almost every single moment - fires, floods, tornadoes, earthquakes, tsunamis, etc. However, human factors can also cause catastrophes, such as war, terrorism, hazardous waste leaks, refugee crises, and so forth. The purpose of humanitarian aid is to provide food, water, medicine, shelter, and supplies to areas affected by large-scale emergencies (Beamon and Balcik, 2008). Logistics actually serves as a link between disaster readiness and response (Thomas, 2003). Procurement and transport in a logistical function are often one of the most expensive aspects of aid operations (Thomas and Kopczak, 2005).

2.1 Characteristics of humanitarian logistics

Humanitarian organizations find it difficult to achieve their goals due to a lack of customer pressure (Tomasini and Van Wassenhove, 2009). As natural disasters are unpredictable, the demand for goods is also unpredictable in terms of time, location, species, and size (Cassidi, 2003; Murray, 2005; Roh, 2012). Therefore, it is difficult to rely on information for humanitarian relief supply chains (Beamon and Balcik, 2008). The main characteristics of humanitarian logistics are impudence and insecurity. It is possible to predict some crises in advance, but many happen without warning. Technology is becoming more advanced every day, which makes it easier to forecast natural disasters more accurately. The next characteristic is timeliness and urgency. Losses and severity after a disaster, are depended on the speed of humanitarian logistics (Kušter, 2021) Time delays can lead to loss of life (Roh, 2012). Additional characteristic is poor economic efficiency. In disasters, the safety of people and their property is the number one prioritiy, while economic issues and costs are secondary. There are four phases of humanitarian logistics: preparation, reaction, recovery, and mitigation (Kilibarda, 2012). The first phase is the preparation phase which includes the procurement, allocation and storage of supplies and the design of an efficient logistics structure. The location of the humanitarian logistics center is characteristic of this phase. The reaction phase occurs after a crisis event. In this phase, the activities are focused primarily on saving lives and preventing major consequences. This phase is considered the most important as the speed of reaction depends on the consequences of a catastrophe or an extraordinary event. The last phase refers to providing the necessary aid in order to achieve the pre-accident state. The characteristics that distinguish humanitarian logistics from traditional logistics are unpredictability, uncertainty, and unconventionality. Furthermore, strategic goals, user and demand characteristics, and environmental factors are distinguished as well (Balcik and Beamon, 2008). Humanitarian logistics is funded by the public sector and charitable donations, whereas traditional logistics derives its revenue from the sale of products and services to customers. In humanitarian logistics, the motivation is not profit, and the goal is not to reduce costs but to increase the efficiency of activities (Roh, 2012).

2.2 The importance of locating a humanitarian logistics center

When a disaster occurs, humanitarian organizations can procure aid supplies from three main sources: local suppliers, global suppliers, and humanitarian logistics centers (Balcik and Beamon, 2008). In the early phases of a disaster, most of the critical supplies arriving in affected areas come from humanitarian logistics centers where supplies are pre-positioned (Balcik and Beamon, 2008). Costs are the main reason for pre-positioning supplies, as it is possible to purchase supplies at a reasonable price (Salisbury, 2007). When disaster happens, demand for supplies increases dramatically, and suppliers will often raise their prices as a response to that (Beamon and Balcik, 2008). Pre-positioning supplies is closely related to the preparation phase and provides a rapid response when a disaster occurs (Tatham and Kovacs, 2007). The primary purpose for establishing emergency supplies is to support life-saving operations during the first few days after a sudden onset disaster, providing the almost immediate delivery of necessary relief items (United Nations Humanitarian Response Depot - UNDHA, 1994).

The location of the humanitarian logistics center is of great importance since it determines the success of the prompt response to the following disaster. Selecting humanitarian logistic center location in humanitarian logistics has also attracted a great deal of attention from humanitarian organizations in recent years. The world's largest humanitarian aid organizations, such as the World Food Program (WFP), the International Federation of Red Cross and Red Crescent Societies (IFRC) and Action Against Action Against Hunger (AAH), have started deploying strategic pre-positioned warehouses worldwide – humanitarian logistics centers (Bolturk et al., 2016).

There are several challenges that need to be overcome in order to ensure the smooth flow of the relief logistics within humanitarian logistics centers. First, the difficulty in creating an effective pre-positioning plan includes uncertainty whether disasters will occur or not and, if they do, where they will occur and to what extent (Rawls and Turnquist, 2010). Although pre-positioned stocks in humanitarian logistics centers may be useful in some cases, their utility may be limited as they require significant financial investment (Chaikin, 2003). The challenge for logisticians consists of proposing the location of a humanitarian logistics center out of reach of the potential disaster, while at the same time ensuring sufficient disaster proximity to deliver aid quickly and efficiently (Balcik and Beamon, 2008). Therefore, locating a humanitarian relief logistics center is a complicated multi-criteria problem.

3. PROMETHEE METHOD

Multi-criteria decision-making (MCDM) methods mainly consist of two parts. The first part determines the weights of the criteria, and the second part evaluates the alternatives in relation to them. In this paper, the criteria weights are determined by decision square matrix. The importance of the criterion is assessed as follows: grade 1 is used when one criterion is more important or dominant in relation to another (if the criterion c_i is dominant, it receives a grade of 1, and the criterion c_j is a grade of 0); a score of 0.5 is used when the criteria are of equal importance, i.e. when there is no more dominant criterion; a grade of 0 is assigned to a criterion that is less important, i.e. which is inferior to the other criterion (if the criterion c_i is inferior, it receives a grade of 0, and the c_j criterion receives a grade of 1).

In this paper, the multi-criteria method PROMETHEE (Brans, 1982), more precisely PROMETHEE II, is used to solve the problem of selecting the best location. The essence of the PROMETHEE method is in determining the preference of each alternative compared to each other, according to each of the criteria, using the preference function in order to acquire the rank of alternatives, either partial or complete (Dimitrijević, 2017). One alternative dominates the other if it performs as good as the other on all criteria, and better than another by at least one criterion, which is expressed by the relation of preference. The relation between two equally good alternatives by all criteria, i.e. mutually equal alternatives, is expressed by the relation of indifference. When one alternative performs better on a criterion c_s and the other one is better on criterion c_r, it is impossible to decide which the best one without additional information is. Therefore both alternatives are incomparable. The characteristic of the PROMETHEE method is the existence of six defined preference functions (Brans, 1982). It is used to reduce the difference in values for each pair of alternatives from 0 to 1, according to each criterion. Thus, it achieves both normalization of values in the matrix and obtaining information on the preference (dominance) of each alternative in relation to each on all the criteria. Further resolution procedure of multi-criteria task using the PROMETHEE method, is presented in algorithmic form.

Step 1. - *defining the mutual preference of alternatives*, $P(A_1,A_2)$, for each pair of alternatives from the set of alternatives A, in accordance with the selected types of preference functions and the parameters of these functions.

Step 2. - *forming the preference index for each pair of alternatives* according to the formula:

$$\pi(A_1, A_2) = \frac{W_j}{\sum_{j=1}^{n} W_j} \sum_{j=1}^{n} \left(W_j \cdot P_j(A_1, A_2)\right). \quad (1)$$

This characteristic shows the preference of alternative A_1 in relation to alternative A_2, though taking into account all the criteria at the same time, regardless $P_j(A_1,A_2)$, which also shows the preference of A_1 in relation to A_2, but only by j-criterion.

Step 3. - *forming the preference index matrix* (Table 1):

Table 1. *Preference index matrix*

	A_1	...	A_m
A_1		...	$\pi(A_1,A_m)$
⋮	⋮		⋮
A_m	$\pi(A_m,A_1)$	...	

Step 4. - *Calculating the positive* $\Phi^+(A_1)$ *and negative* $\Phi^-(A_1)$ *characteristics* for each alternative from set A:

$$\Phi^+(A_1) = \frac{1}{m-1} \sum_{x \in A} \pi(A_1, x) \quad . \quad (2)$$

$$\Phi^-(A_1) = \frac{1}{m-1} \sum_{x \in A} \pi(x, A_1) \quad . \quad (3)$$

$\Phi^+(A_1)$ presents how much alternative A_1 is better than all other alternatives from the set of alternatives A, on all criteria from the set of criteria K. Logically, $\Phi^-(A_1)$, presents the opposite information, i.e. how much all other alternatives are better than alternative A_1.

Therefore, based on these characteristics, the final ranking of alternatives in relation to the total preference of alternative A_1 ($\Phi(A_1)$), can be calculated as follows:

$$\Phi(A_1) = \Phi^+(A_1) - \Phi^-(A_1). \qquad (4)$$

According to the PROMETHEE II method, alternative A_1 is *preferable* to alternative A_2 if the following is fulfilled:

$$A_1\, P^{II}\, A_2 \;\; if \;\; \Phi(A_1) > \Phi(A_2) \qquad (5)$$

Alternative A_1 is *indifferent* to alternative A_2 if:

$$A_1\, I^{II}\, A_2 \;\; if \;\; \Phi(A_1) = \Phi(A_2) \qquad (6)$$

4. CASE STUDY – LOCATION SELECTION OF HUMANITARIAN LOGISTIC CENTER IN SERBIA

When it comes to catastrophes that happened in Serbia, floods have the largest part. The last major floods in Serbia occurred in 2014. On that occasion, 22% of the population was affected and damages of 1.7 billion euros were caused. In 2006, about 225,000 hectares of fertile land were flooded, and the damage was estimated at 35.7 million euros. The biggest flood in Serbia happened in 1965, when the river Danube overflowed, which affected almost all river flows, and about 150,000 hectares of land, 16,000 houses and 214 kilometers of roads were under water. When it comes to earthquakes, the most devastating earthquake happened in Kraljevo in 2010, when 200 people were injured, while about 850 households were destroyed. Some of disasters that have impacted Serbia in previous years are fires, storms, and landslides. However, as the floods have caused the greatest damage so far, alternatives will be considered first in relation to the possibility of rivers overflowing.

4.1 Problem structure, criteria, and alternatives

The proposed model is used for the selection of humanitarian logistic center locations for the territory of Serbia. For HLC selection, the following criteria are selected: proximity to disaster-prone areas - c_1, availability of logistics experts - c_2, geographical characteristics - c_3, transport connectivity - c_4, availability of existing facilities and infrastructure - c_5, land price - c_6, number of logistics providers - c_7. In literature, proximity to disaster-prone areas is the most dominant factor when it comes to the location selection of humanitarian logistic centers (Roh, 2022). HLC location impacts directly the response time and costs of providing aid (Balcik i Beamon, 2008). The availability of logistics experts is another dominant factor that is related to the availability of trained and qualified staff. The quality of HLC functioning directly depends on knowledge and experts' qualifications. Geographical characteristics refer to the physical characteristics that describe the natural environment of the place (relief, rivers, climate, etc.). Transport connectivity implies the availability of transport infrastructure between the potential location of the HLC and the site of the disaster. It considers the existence and proximity of the airports and ports as well. Since the aim of humanitarian aid is to deliver humanitarian supplies as soon as possible to the users after the disaster, the availability of airports is an extremely important factor for emergency operations. The criterion related to existing facilities and infrastructure considers the existence of facilities that can be used for the purpose of storing humanitarian aid supplies, facilities that provide electricity, water, and vehicle maintenance services, and other facilities that support the work of HLC (Roh, 2022). Before locating the humanitarian logistics center, it is necessary to consider the proximity of regional logistics centers. Land price is one of the criteria that must be included in the cost analysis. The criterion of the presence of logistics providers is significant not only because of their existence but also because of the necessary cooperation between them.

The following cities in Serbia were chosen as potential locations of the humanitarian logistics center: Novi Sad - HLC_1, Belgrade - HLC_2, Kragujevac - HLC_3 and Niš - HLC_4. Novi Sad is extremely convenient from the aspect of transport connections, which is proved by the fact that it is one of the most important hubs in Serbia, next to Belgrade and Niš. There is no airport in Novi Sad. The city is not risky in terms of environmental catastrophes, and it is more protected from earthquakes compared to other alternatives, hence there is a possibility of Danube overflowing. The largest hub of Serbia is Belgrade, which occupies the best transit position. The "Nikola Tesla" Airport in Belgrade has a large capacity and significantly affects the transport connections of this city. The buoyancy of rivers is excellent, but there is a risk of river overflow. A large number of residents are present, which is positively characterized. Thus, by locating a humanitarian logistics center in this city, help can be provided to a large number of people. The availability of logistics experts is advantageous in Novi Sad and Belgrade. The transport connection of Kragujevac does not reach the levels of transport connections of other alternatives, there are no waterways nor airport, but the airports in Belgrade, Kraljevo or Niš can be reached promptly. According to the criteria of land prices, location in Kragujevac is optimal. Niš has an excellent geoposition and is a great hub of Serbia. It has an airport that does not have a large capacity, though it is very busy and has a positive impact from the aspect of transport connections. From the aspect of proximity, it is favorable because it can cover risk areas from floods due to problems around the Morava and its tributaries. In addition, there is already a Serbian-Russian humanitarian center in Niš, which could provide the necessary support in case of need.

4.2 Determining criteria and evaluation alternatives

The criteria weights were determined by using a square matrix (Table 2). According to the results, the dominant criterion is the proximity of the area of susceptible catastrophes (c_1) due to the fact that the factor of rapid response is crucial when acting in crisis situations. Furthermore, the most important criteria are the availability of logistics experts (c_2), transport connectivity (c_4) and the number of logistics providers (c_7).

Table 2. Weight coefficients of criteria decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Σ
C_1	/	0.5	1	0.5	1	1	0.5	4.5
C_2	0.5	/	1	0.5	0.5	1	0.5	4
C_3	0	0	/	0.5	0.5	0.5	0	1.5
C_4	0.5	0.5	0.5	/	1	1	0.5	4
C_5	0	0.5	0.5	0	/	0.5	0.5	2
C_6	0	0	0.5	0	0.5	/	0	1
C_7	0.5	0.5	1	0.5	0.5	1	/	4

In relation to the criteria which the weights were obtained for, the alternatives are evaluated according to the criteria using the linguistic terms given in Table 3, where each term is assigned a numerical value, from 1 to 5.

Table 3. Criterion values and corresponding linguistic descriptions

Value	Linguistic term
1	Most unfavourable
2	Unfavourable
3	Medium favourable
4	Favourable
5	Most favourable

The evaluation of potential locations of the humanitarian logistics center is given in Table 4.

Table 4. Evaluation of potential HLC locations according to criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
	max	max	max	max	max	min	max
HLC_1	4	4	5	4	5	5	5
HLC_2	5	5	3	5	4	5	5
HLC_3	2	3	4	3	3	3	4
HLC_4	4	4	3	5	4	4	4

In order to solve the problem, the Visual PROMETHEE software tool was used, i.e. to determine the rank of potential locations based on the displayed data. Aiming to determine criteria for disaster-prone areas proximity, availability of logistics experts, transport connectivity and number of logistics providers, a linear preference function (V-shape) with parameter 2 was used, where preference is expressed in value between 0 and 1. Therefore, if the difference in the value of the HLC_i - HLC_j alternative is greater than 2, according to this criterion, then we prefer the HLC_i alternative (preference function equal to 1). If the difference HLC_i - HLC_j is between 0 and 2, the preference function takes a value between 0 and 1. Previously mentioned four criteria are the most important for the analysis, the application of the linear preference function takes into account the smallest deviation. For other criteria, a usual preference function is used, without parameters. For these criteria, the higher (the less) value, that is better for choosing the appropriate alternative for the maximization (minimization) type of criteria. The obtained results are shown in Table 5.

Table 5. Ranking potential locations using the Visual PROMETHEE tool

Location	Phi	Phi+	Phi-	Rank
HLC_2	0,3529	0,4902	0,1373	1
HLC_1	0,1716	0,3725	0,2010	2
HLC_4	0,1225	0,3235	0,2010	3
HLC_3	-0,6471	0,1176	0,1176	4

According to results, HLC_2 – Belgrade was obtained as the best alternative, while HLC_1 – Novi Sad was in second place. In order to avoid subjectivity in the evaluation of variants, it is necessary to do more iterations, i.e. to conduct sensitivity analysis. For this purpose, three more iterations were made. In the first iteration, all functions of preference are equalized, i.e. a simple preference function without parameters was chosen. In the second iteration, the weight coefficients are equal for all criteria, i.e. value 1 was taken for the weight of each criterion. In the last iteration, the preference functions and weight coefficients are equalized. The results are presented below. The results obtained in these iterations are shown in Tables 6, 7 and 8, respectively. It can be seen that in the first iteration the best alternative was HLC_2 – Belgrade, while in the second place is HLC_4 – Niš. In the second iteration the best is the first alternative HLC_1 – Novi Sad, while in the second place is HLC_2 – Belgrade. Finally, in the last iteration the best alternative is HLC_2 – Belgrade, and the other is alternative HLC_1 – Novi Sad. Having in mind all three iterations, the alternative HLC_3 – Kragujevac is the worst positioned.

Table 6. Results of iteration 1 using the Visual PROMETHEE tool

Iteration 1	Phi	Phi+	Phi-	Rank
HLC_2	0,5588	0,6961	0,1373	1
HLC_4	0,1176	0,4020	0,2843	2
HLC_1	0,0882	0,4510	0,3627	3
HLC_3	-0,7647	0,1176	0,8824	4

Table 7. Results of iteration 2 using the Visual PROMETHEE tool

Iteration 2	Phi	Phi+	Phi-	Rank
HLC_1	0,2222	0,4444	0,2222	1
HLC_2	0,0833	0,3611	0,2778	2
HLC_4	0,0556	0,3333	0,2778	3
HLC_3	-0,3611	0,2778	0,6389	4

Table 8. Results of iteration 3 using the Visual PROMETHEE tool

Iteration 3	Phi	Phi+	Phi-	Rank
HLC_2	0,2222	0,5000	0,2778	1
HLC_1	0,1667	0,5000	0,3333	2
HLC_4	0,0556	0,3889	0,3333	3
HLC_3	-0,4444	0,2778	0,7222	4

Based on the results, the conclusion is that in the case of Serbia, the best location for the humanitarian logistics center would be in Belgrade. Novi Sad, as the best in the second iteration and the second best in the third iteration, takes second place for the potential location of the HLC. Belgrade and Novi Sad are suitable primarily from the aspect of proximity to disaster-prone areas. Vojvodina is considered as one of the areas prone to floods, where in 1965 the largest flood in Serbia took place, it is close enough to Belgrade to react in case of new catastrophes. At the same time, Belgrade is far enough away from potential disaster. However, for the micro-location of the logistics center that would be located in Belgrade, it is necessary to take into account two large rivers - the Sava and the Danube. The micro-location of the humanitarian logistics center should be far enough distanced from the area that could be affected by the overflow of the previously mentioned rivers. On the other hand, their potential can be used to deliver large quantities of goods intended for humanitarian aid. Belgrade is interconnected with other Serbian cities which allows access to all parts of Serbia where disasters could potentially occur. The reason why Belgrade and Novi Sad stand out is the presence of logistics experts and the number of logistics providers who, through cooperation and adequate coordination, would be vitally important in providing humanitarian aid. The disadvantage is the price of the land. Belgrade is considered to be a area with the highest land prices, but the price in the case of providing assistance to the endangered is not the most relevant factor, but speed and efficiency.

5. CONCLUSION

The problem of locating the humanitarian logistics center is substantial and complex. The efficiency of providing humanitarian aid to a great extent depends on the location of the humanitarian logistics center. Immediate response in unexpected circumstances may be aided by the HLC location. In this paper, the multicriteria PROMETHEE method was used to rank and select the HLC location. The application of this method is presented in solving the case of Serbia. Due to the complexity of solving the problem of locating and the present uncertainty, it is necessary to consider several criteria and include expert opinion. Future research could relate to considering the micro-location of the center, considering several criteria, or involving more stakeholders in the decision-making process.

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STOCHASTIC FINANCIAL EVALUATION OF INTERMODAL TERMINAL DEVELOPMENT

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Abstract: *Intermodal terminals (IMTs) have significant importance in logistics networks whose development enables the implementation of intermodal transportation technologies and participation in international goods flows. This article analyzes the financial risks of investing into an IMT in Belgrade (Republic of Serbia). The scientific contribution of the article is in being the first to use a stochastic financial evaluation model for assessing the development of an IMT. The article analyzes the financial risk probability over real-world data, considering the stochastic nature of container flow volumes and the prices of logistics services. The risk probability, as an output result of the used simulation model, is derived from the probability distribution of three distinct financial parameters – net present value (NPV), internal rate of return (IRR), and the benefit-cost ratio (B/C). The results of the analysis indicate that the development of the IMT is financially justified, with relatively low investment risk.*

Keywords*: intermodal transportation, intermodal terminal, stochastic analysis, net present value, internal rate of return, benefit-cost ratio*

1. INTRODUCTION

In the countries of the European Union (EU), the growth rate of logistics industry, the key area that supports economic development, is higher than the average economic growth rate of those countries (EC 2009). The development of logistics systems is the key for achieving regional competitiveness, economic prosperity, and sustainable development (Tadić et al. 2021).

The growth of living standards and the individualization of customer demands caused the need for developing and managing efficient logistics systems. Furthermore, the ongoing global trend is to strive towards the reduction of road transportation involvement in the overall freight transport by a modal shift towards more eco-friendly transportation modes – such as rail and inland waterway transportation modes. Obviously, intermodal transportation stands out as a sustainable development direction of regional, European, and global logistics networks.

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To ensure the sustainability of intermodal systems, it is necessary to develop appropriate infrastructure, whose key elements are intermodal terminals (IMTs) (Ližbetin 2019). Determining the location, subsystem structure, and the role of IMTs represent some fundamental problems that require attention while modelling intermodal networks (Caris et al. 2008) and their solving should be executed in the context of financial and economic assessment.

This article uses a stochastic financial evaluation model for assessing the development of an IMT in Belgrade. The analysis is performed through three different financial parameters – net present value (NPV), internal rate of return (IRR), and the benefit-cost ratio. By applying the simulation-analytical model the probability distributions of observed parameters are derived. Based on those distributions, the investment risk of the IMT is determined. The main contribution of this article is in being the first one to financially assess IMT development in a stochastic environment for real-world terminal development data.

The article is organized into five sections. The next section presents a short literature review of intermodal transportation, the funding of intermodal transportation projects, and the stochastic approach to solving problems in that area. Section 3 explains the stochastic approach used for the analysis. Section 4 presents the case study for which the financial assessment is performed. Section 5 presents the result analysis. At the end, the concluding section is presented.

2. LITERATURE REVIEW

Intermodal transportation represents the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes (ECMT 2001). Positive effects that follow the application of intermodal transportation are reflected by the reduction of energy use, time, costs and negative environmental effects of transport. Obviously, intermodal transportation stands out as one of the key factors for achieving sustainable development.

In developed countries of the European Union (EU), intermodal transportation has an institutionalized character and clearly defined models for funding its development exist (Tadić et al. 2017). Having in mind that the majority of developed European intermodal networks are concentrated in its western parts, southern and southeastern Europe falls back greatly (Tadić et al. 2021). The integration of countries into the European logistics and transportation system, as well as in the realization of international goods flows, is not possible without the application of intermodal technologies.

IMTs, as one of the main subsystems of intermodal transportation, represent facilities where intermodal units' storage and transshipment between different transportation modes takes place. IMTs are vital nodes of every intermodal network and they stand out as important catalysts of regional economic development.

Logistics networks are systems composed of nodes and connections between those nodes. In general, the nodes of a logistics network represent the origins and final destinations of goods flows, and they can be facilities, warehouses, logistics centres, IMTs, ports, etc. (Janic 2007). The links between network nodes are established with road or rail infrastructure, or via inland waterways. IMTs represent complex systems which can differ in their function, role, subsystems, users, applied technologies, etc. (Krstić 2019).

Regions that do not possess appropriate logistics infrastructure and which are not included in an intermodal network become uncompetitive in the logistics service market. The trade of these regions is penalized, which leads to the dislocation of goods and services into better-serviced regions (Monios 2015). Infrastructural investments are of vital importance for the development of logistics infrastructure and so for the economic activity of a state/country/region as well.

The development of IMTs is followed by high investments and long construction periods, as well as a low return rate of the investments. Having this in mind, it is obvious that individual engagement of the private sector in this area is rare. During the development of intermodal systems, large amounts of funding and subsidies are required before any profits begin to happen, therefore state intervention is required when developing intermodal networks (Wiegmans and Behdani 2017). High investments and potential investment risks stimulate public-private partnerships (PPP) in funding the projects of intermodal transportation.

PPP refers to different collaboration forms of public authorities and the private sector with the goal of funding, construction, restoration, management, and maintenance of infrastructure or providing services (EC 2004). The forming of PPP is a result of recognizing the gains from joining financial assets, knowledge, and skills with the goal of improving certain activities or services. Through PPP, the public and private sectors share costs, risks, responsibilities, and benefits (Ittmann 2017). The main motive for the private sector for joining a PPP for the projects of intermodal transportation is better opportunities for offering a wider set of logistics services and a larger profit, while the state gains modal shift (from road to rail/inland waterway modes) and stimulates regional sustainable development.

Defining an appropriate PPP model is a complex task when developing IMTs. The public sector has to define the partnership model in a way to minimize uncertainties and risks, but at the same time, to make it attractive for the private sector (Nguyen and Notteboom 2017). Defining a PPP represents a serious challenge for developing countries because they lack collaboration experience between the public and private sectors in the projects of intermodal transportation.

A large number of external factors that influence the realization of intermodal chains and their complexity give the problems of intermodal transportation stochastic traits, therefore simulation stands out as an appropriate tool for their solving (Crainic et al. 2018). In the existing literature, simulation has been used for solving various problems in the field of intermodal transportation, such as locating IMTs (Vidović et al. 2011), modelling intermodal networks (Yang et al. 2016), allocating resources in intermodal systems (Wang et al. 2017), container flow volumes prediction (Meng and Wang 2011), terminal capacity dimensioning (Özkan et al. 2016), etc.

The article (Tadić et al. 2020) conducts a financial analysis of developing an IMT in Belgrade but in a deterministic environment. It is concluded that the development of an IMT is financially justified, but the authors point out that analysis in a stochastic environment is necessary in order to determine the investment risks in such a project. The article has shown that the financial justification of developing an IMT is more sensitive to the changes in container flow volumes than to the changes in terminal service charges. The article (Raicu et al. 2012) analyzes different development scenarios of an IMT in Bucharest, where the scenarios differ in the terminal services.

This article uses a simulation model to determine the investment risks of an IMT in Belgrade from the aspect of three financial parameters – NPV, IRR, and B/C. In contrast with the article (Raicu et al. 2012) where only terminal service prices are a variable, this article considers also variable container flow volumes. Based on the container flow volumes and terminal service prices, the financial flows of the terminal are determined and so are the probability distributions of the observed parameters as well.

3. STOCHASTIC APPROACH IN THE FINANCIAL ANALYSIS OF AN IMT DEVELOPMENT

When designing logistics systems, stochastic factors that mostly have an impact on the system are demand characteristics which refer to the type, assortment, and the quantity of goods, demanded delivery time, the service itself, etc. It is not unusual for a logistics system to be unable to serve all the demands because of the lack of capacities or to have wasted capital due to underutilized capacities. These situations are mostly the consequence of inadequate understanding of factors that impact the development and exploitation of a logistics system.

In the context of intermodal transportation, container flows volume on a certain relation is a probabilistic variable. Despite that a trend line for container throughput could be identified and predicted, it is common for the volumes to deviate significantly from the predicted values. Considering the complexity of all the factors that influence these deviations, there is no model that could precisely determine the container flow nature over a longer time period. Furthermore, logistics service prices are also a variable category. Service prices of an IMT are tightly bound to the global and local state of the economy, and political circumstances, but also to the competition in the logistics services market.

The traditional approach to calculating financial parameters does not take into account the stochastic nature of all the factors that impact their value. Therefore, a simulation is recognized as a suitable method for calculating the financial parameters' value in a stochastic environment. The stochastic approach to determining financial parameter value enables the decision-maker better insights into the investment risks of a project (Shaffie and Jaaman 2016). In stochastic approaches for determining financial parameters, with probability distributions as input data, the output results (financial parameters) are also in the form of probability distributions (Tziralis et al. 2009). Three financial parameters are considered in this article – NPV, IRR, and B/C.

NPV is one of the standardized project evaluation and selection parameters and it takes into consideration the time value of assets. The calculation of NPV includes the discount of all future asset inflows and outflows. A project will be accepted if the NPV is positive, or refused if NPV is negative. IRR represents the discount rate for which the NPV of the project equals zero. When the value of IRR is greater than the actual interest rate, the observed project is financially acceptable. By comparing the discounted values of benefits and costs the benefit/cost ratio (B/C) is calculated. In other words, B/C represents the relation of present values of benefits and costs. An investment project is accepted if the value of B/C equals/is greater than 1 (Petrović-Vujačić et al. 2019).

Considering the stochastic nature of all the factors that influence the costs and profits of an IMT, the input parameters and data are probability functions and therefore NPV, IRR, and B/C, as output parameters, are in the shape of probability distributions as well. Based on the probability distributions of the output parameters, the financial risks of the project can be easily determined.

For the financial evaluation of the IMT development a simulation model, based on the article (Zaman et al. 2017), is developed. The model simulates the stochastic nature of all input parameters and determines the probability distributions for NSV, IRR, and B/C. From these probability distributions, IMT development investment risks can be determined. From the aspect of NPV, the risk is represented as the probability that the project NPV value would be negative or equal to zero, while from the aspect of IRR, the risk is represented as the probability that the IRR value would be lesser than the project discount rate. According to B/C, the risk is represented as the probability that the B/C would take values below 1.

4. IMT IN BELGRADE AND INPUT DATA

The IMT in Belgrade (Batajnica, 15 km away from the city centre) is in the focus of this article analysis. The analysis is performed in the context of the data from (Tadić et al. 2020, EC 2012) but in a stochastic environment. The predicted terminal container flow throughput volumes are presented in Table 1.

Table 1. Predicted container flow volume over time (Tadić et al. 2020, EC 2012)

Year	Container throughput (TEUs)	Growth (%)	Year	Container throughput (TEUs)	Growth (%)
2013	0	0	*2028*	54880	2.3
2014	3200	0	*2029*	61040	11.2
2015	15960	398.8	*2030*	65520	7.3
2016	21000	31.6	*2031*	70611	7.8
2017	27300	30	*2032*	74055	4.9
2018	30660	12.3	*2033*	77499	4.7
2019	33460	9.1	*2034*	80943	4.4
2020	34580	3.3	*2035*	84387	4.3
2021	38080	10.1	*2036*	87831	4.1
2022	44240	16.2	*2037*	91275	3.9
2023	46480	5.1	*2038*	94719	3.8
2024	47320	1.8	*2039*	98163	3.6
2025	51100	8	*2040*	101607	3.5
2026	53620	4.9	*2041*	105051	3.4
2027	53620	0	*2042*	108495	3.3

When designing any logistics centre, a wrong assumption regarding the goods flows throughput volumes can lead to catastrophic consequences. The acceptance of any logistics-related project has to be accompanied by appropriate risk and sensitivity analyses. Considering the stochastic nature of goods flows through time, project financial analysis should also include possible parameter deviations from the predicted values. In this article, it is assumed that the expert predictions of container flow volumes would vary between -50% and +50%. Three container flow volumes deviation scenarios are considered: pessimistic, realistic, and optimistic (Figure 1). For every scenario, a probability distribution of the flow volume deviation is defined. The occurrence probability for the realistic scenario is 0.4, while the occurrence probability for the other two scenarios is 0.3 for both.

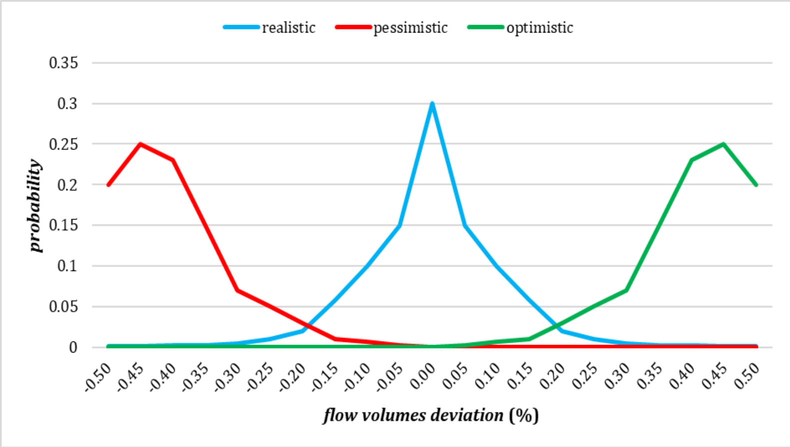

Figure 1. Container flows volume deviation scenarios

The development of the IMT in Belgrade is planned to be executed through two operational phases (EC 2012). Both phases refer to specific type of construction works and require specific investments. Since the construction and development expenses of an IMT are extremely high, it is assumed that the private investor would take loans. All the data regarding the development phases, their dynamics, required investments, loan repayment, and other assumptions are taken from (EC 2012) and are explained in detail in the article (Tadić et al. 2020).

Table 2. IMT services prices (EC 2012)

<table>
<tr><td>Service</td><td colspan="3">Price</td><td>Service</td><td colspan="3">Price</td></tr>
<tr><td>Manipulation with ITUs</td><td colspan="3">39 €/manipulation</td><td rowspan="2">Road transportation planning</td><td>In the boundaries of logistics zone</td><td>On the territory of Belgrade</td><td>Outside of Belgrade</td></tr>
<tr><td rowspan="4">ITU storage</td><td>First three days for importing containers and one day for exporting containers is this service free of charge</td><td>For containers</td><td>For EITUs</td><td>80 €</td><td>144 €</td><td>190 €</td></tr>
<tr><td>Storage for the next 5 days</td><td>16 €/day</td><td>29 €/day</td><td rowspan="2">Parking</td><td>First two hours</td><td colspan="2">After the first two hours</td></tr>
<tr><td>Storage for the next 2 days</td><td>34 €/day</td><td>68 €/day</td><td>Free of charge</td><td colspan="2">7.5 €/h</td></tr>
<tr><td>Storage for the next 2 days</td><td>57 €/day</td><td>99 €/day</td><td>Cancelling fees</td><td colspan="3">85 €/cancellation</td></tr>
<tr><td>Specialised ITU storage</td><td colspan="3">Additional 30% on the prices for standard ITUs</td><td>Container inspection fees</td><td colspan="3">17 €/container</td></tr>
</table>

Terminal service prices directly impact the amount of profits during its exploitation cycle. Having in mind that all the factors that dictate terminal service prices are variable, it is assumed that the prices may vary over time as well. Basic terminal service prices are shown in Table 2. Inadequate assumption of future terminal service prices might form an unrealistic picture of expected profits. In this article, the terminal service prices might vary from the basic values in a predefined range. The probability distribution of terminal service prices deviation is presented in Figure 2.

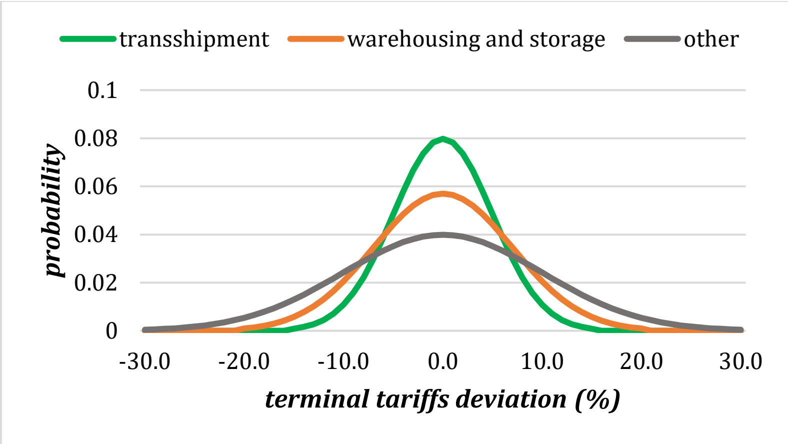

Figure 2. Probability distribution of possible terminal service prices deviation

Annual IMT expenses can be divided into fixed and variable expenses (Table 3). All terminal exploitation profits and expenses are evaluated according to real-life and the (EC 2012) project data.

Table 3. IMT fixed and variable expenses (Tadić et al. 2020; EC 2012)

Fixed expenses	*Expenses*	*Variable expenses*	*Expenses*
Energy, telecommunications, Internet	30000 €/year	*Personnel salaries and expenses*	17155 €/employee
Office equipment	22500 €/year	*Manager salaries and expenses*	32740 €/employee
Service insurance and taxes	57500 €/year	*Annual training, control and inspection costs*	10 % of employee costs
Fixed maintenance costs	333000 €/year	*ITU manipulation electricity expenses*	1.45 €/ITU
Freight village developer fees	160000 €/year	*Road transportation planning expenses*	100 €/truck

5. RESULT ANALYSIS

According to the simulation model, the NPV values range between -7 and 18 million € for a period of 30 years (Figure 3). The most probable NPV (with a probability of 0.12) is 5 million €. The investment risk according to NPV is 11.3%.

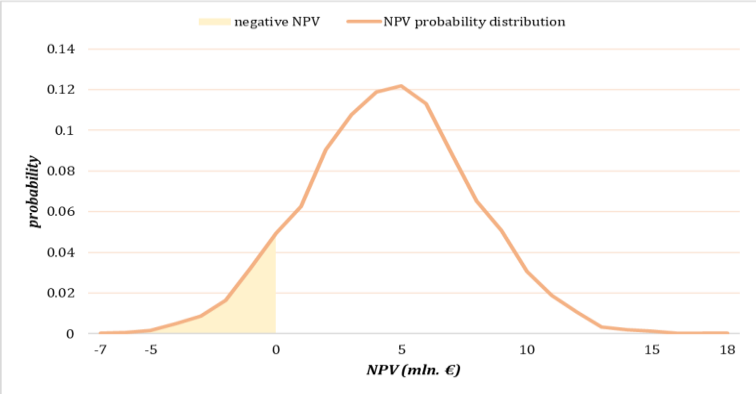

Figure 3. NPV probability distribution

According to IRR, the results differ from those of NPV, but from the perspective of investment risks, they are the same since IRR and NPV are mathematically complementary parameters. The values of IRR are in the range between 1% and 18%, where the most probable value is 8% (with a probability of 0.22). As is the case with NPV, the investment risk is 11.3% (Figure 4).

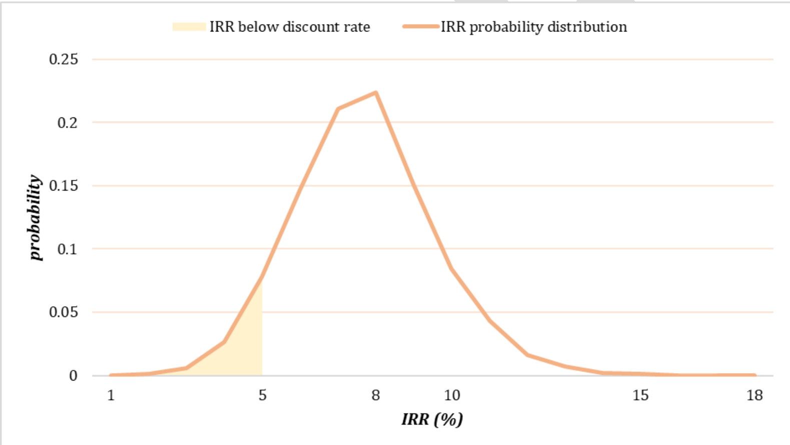

Figure 4. IRR probability distribution

The values of B/C are in the range between 0.9 and 1.3, while the most probable value is 1.1 (with a probability of 0.39). According to the probability distribution of B/C, the investment risk is 6.81% (Figure 5).

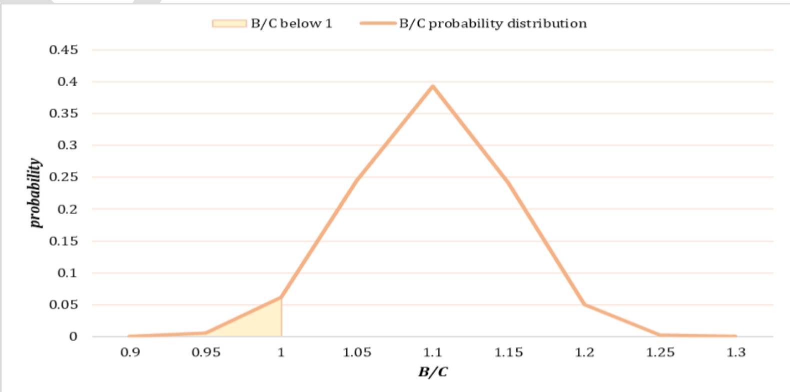

Figure 5. B/C probability distribution

6. CONCLUSION

This article presented a stochastic financial analysis of an IMT in Belgrade. The analysis is performed in the context of three parameters – NPV, IRR, and B/C. A stochastic approach is applied in determining the values of the parameters. Considering the dynamic and stochastic nature of the input parameters and data, the output results are in the shape of probability distributions.

The analysis of the results shows that the development of an IMT in Belgrade is financially justified. The investment risk, according to NPV and IRR is 11.3%, while according to B/C, the investment risk is 6.81%. The most probable NPV is 5 million €, while the most probable IRR is 8%. The value of B/C with the greatest probability is 1.1.

Considering the results, it can be stated that the development of an IMT in Belgrade is financially justified, with relatively low investment risk. The direction of future research could be in the analysis of the effects that the development of an intermodal system would result in, especially on the economic growth of a country/region. Of course, that should be preceded by a more detailed analysis of the required number of terminals, their location, structure, etc. One of the directions could also be in the analysis of intermodal technologies that justify its system development and application in developing countries and regions.

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HOUSEHOLDS IN THE FUNCTION OF COLLECTION AND DELIVERY POINTS: LOCATION DECISION PROBLEM

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Abstract: *One of the home delivery models that have become increasingly important in recent decades is delivery to the collection and delivery point (CDP). This can be a commercial facility with staff (trade, catering, service facilities) or without staff (automated packing stations, parcel lockers). This paper discusses the idea that the role of CDPs is performed by households of customers, in order to reduce flows, distance traveled, costs and other negative effects, and presents the procedure of household selection, i.e. locating CDPs using the median location problem. The problem was solved on a hypothetical example for the City of Belgrade. Two strategies have been defined, locating the median in each zone of the service area and locating one median for the entire service area. The location of one median was done in two ways. In the first case, real distances between potential locations were used, medians in each zone were used as potential locations for CDPs, a linear programming task was defined, and a solution was obtained using a solver. In the second case, Euclidean distances and an algorithm for determining a single median were used. In both cases, the same solution was obtained.*

Keywords: *home delivery, collection and delivery point, household, location problem, median.*

1. INTRODUCTION

In recent decades, under the influence of Internet ordering and e-commerce, the home delivery service, i.e. delivery of goods to customers, has been intensively developed. This segment of the supply chain is often called last mile delivery. Given the territorial dispersion of customers, complex requirements in terms of delivery time, small orders, high percentage of unsuccessful deliveries and return flows, the last mile is the most inefficient and expensive part of the supply chain (Gevaers et al., 2009). In addition, deliveries can lead to an increase in freight transport and the accompanying negative effects (congestion, emissions, noise, etc.).

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In order to overcome these challenges and (or) improve the level of service, different models of home delivery are being developed from the aspect of (Tadić & Veljović, 2021): need for ordering, frequency, ordering and payment system, starting and end point, executors, reception method, security, delivery area, speed and time of realization, characteristics of return flows, applied technology, etc. The classification of the delivery models from the aspect of the end point is especially interesting. Although the name of the service indicates that the goods are most often delivered to the home address, many authors (Visser et al., 2014; Punakivi, 2003; Browne et al., 2001) under the term "home delivery" include deliveries to other locations at the customer's request, such as (Tadić & Veljović, 2021): household of neighbors, friends, relatives, customer's place of work, collection and delivery points, drop-off company, trunk of the customer's car (in this case the location is variable), etc. These locations are used as a targeted (first) or alternative delivery destination (after a failed home delivery).

Collection and delivery point (CDP) is one of the most commonly used solutions for delivering goods to customers. Selecting appropriate facilities and locating CDPs is a very important task and strategic decision for their efficiency (Morganti et al., 2014a), given that the selected location should reduce flows and costs, for the benefit of all stakeholders. Purpose-built or existing facilities with staff (e.g. post offices, shops, restaurants, etc.) or without staff (automated packing stations, parcel lockers) are used as CDPs. On the other hand, the role of CDPs can be played by the customers themselves, i.e. their households (Tadić et al., 2022). Locating CDPs can be done using different location models, e.g. center, median, coverage, etc. Mislocation can lead to overloading of some CDPs and underutilization of others.

Numerous authors have dealt with the concept of CDPs in recent years. Morganti et al. (2014b) analyzed the application of attended and unattended CDPs in Germany and France. Weltevreden (2008) investigated how customers in the Netherlands accept CDPs and what are the effects of their application from the aspect of mobility, as well as the business of trading companies. Zenezini et al. (2018) analyzed the possibilities and obstacles for more mass application of CDPs from the perspective of courier, express and parcel services. Song et al. (2009) investigated the effects of the introduction of various CDPs (post offices, railway stations, retail stores) as alternative destinations after unsuccessful deliveries on the distance traveled, harmful emissions and transport costs and found that their use can bring significant benefits compared to traditional delivery. Wu et al. (2015) used public transport data and historical delivery data to locate unattended CDPs, estimating patterns of population mobility. Wang et al. (2017) developed a location covering model in order to define the optimal network of CDPs so that the scope of covered demand is maximized. Lin et al. (2020a; 2020b) addressed the problem of CDP location and developed a multinomial logit model and Threshold Luce model to assess customer choice in using CDP services.

This paper will present the procedure for selecting a household as a location for CDP in the part of the City of Belgrade, using the p-median location problem, which is the main goal and contribution of the paper. Two strategies will be defined: locating the median in each zone of the service area and locating one median for the entire service area. Locating one median will be done in two ways: as a task of linear programming and with algorithm for determining one median. The paper is organized as follows. After the introduction, the second section describes the concept of CDP. In the third section, the CDP(s) is located in the service area. Finally, concluding remarks and directions of future research are given.

2. COLLECTION AND DELIVERY POINTS

CDPs are a network of locations where suppliers/operators pick up and deliver ordered goods, and customers or consignees pay, collect or return goods (Yuen et al., 2018; Piplani & Sarasvat, 2012). These places are also called: collection points, cluster points, pick-up points, pick-own-parcel points, reception points, etc. (Tadić & Veljović, 2021). There are two variants of CDP, attended (with staff) and unattended (without staff). In the first case, the persons employed in the CDP receive and hand over the goods to the customers, while in the second case the customers pick up the goods themselves, most often from lockers or containers, using the order reference code.

There are numerous advantages of applying CDPs for all stakeholders (Tadić & Veljović, 2021): delivery organizers (minimized number of failed deliveries, enabled consolidation of goods, reduced mileage, number of employees and vehicles, number of vehicle starts, energy consumption, etc.), customers (eliminated need to wait for delivery at home, lower delivery costs, the delivery of goods from the CDP to the home address is most often performed by customers during everyday business trips, shopping, etc., so there are no additional costs, etc.), community and environment (reduced number of flows and thus congestion, demand for parking in residential areas, emissions, customers often deliver from CDP to their home address on foot or by bicycle, which has positive social, health and environmental effects, etc.).

3. LOCATING CDP USING P-MEDIAN LOCATION PROBLEM

As already mentioned, the selection of appropriate facilities and the location of CDPs are strategic decisions for their efficiency, and the wrong location can lead to overloading or underutilization of CDPs. Therefore, locating should be done in accordance with many factors, especially population density, i.e. the density of customers/requests. Accordingly, more CDPs are located in densely populated, urban areas than in rural ones, so their location is closer to the customers. Thus, in some parts of France, the population is 1.6 km from the nearest CDP in urban areas and 6 km in rural areas, which makes customers in rural areas largely dependent on cars (Morganti et al., 2014a). There are also differences in the choice of object type for CDP. In urban areas, CDPs near traffic hubs are most often used as CDPs, while due to the small number of such facilities, unattended CDPs (automated packing stations, parcel locker) are more often located in rural areas (Hübner et al., 2016). The exceptions are post offices, which also often serve as CDPs in rural areas (Browne et al., 2001). Households are a suitable facility for CDPs, both in urban and rural areas for a number of reasons. They are present in both urban and rural areas. There is no need to build additional infrastructure, which requires investment and space, which is particularly congested and expensive in urban areas. Finally, this may be a chance to use the underutilized capacity of households, as well as employment and additional earnings for its members. An informal form of this practice has existed for a long time. For example, there are examples of one tenant receiving and temporarily storing goods for multiple customers from a residential building or a particular neighborhood, or one resident receiving and temporarily storing goods for multiple customers from a rural settlement.

In this paper, the location problem of p-median was used to solve the problem of locating CDP, and its applicability was tested on a hypothetical example for a company in the City of Belgrade. The hypothetical company delivers the goods to the home address of the permanent customers located in 7 zones (Figure 1). The company plans to introduce a new delivery model - delivery to CDP, in order to reduce flows, the number of employees and vehicles, energy consumption and costs, as well as to attract customers with a service that is cheaper than home delivery. The company wants to use the households of its customers as CDPs, with appropriate monetary or other compensation (e.g. reduced price of goods, free delivery, etc.), in order to avoid the cost of investing in CDPs. The company is considering two strategies, the introduction of one CDP for each zone and the introduction of one CDP for the entire service area.

Figure 1. Service zones and locations of customers

CDP was located using the p-median (p = 1) location problem. This problem was first formulated by Hakimi (1964). It involves locating a predetermined number of objects on the network, so as to minimize the average distance, travel time or transport costs from the object to the customer or vice versa. This problem and its extensions are useful for modeling in many situations, such as locating industrial plants, warehouses, public institutions, etc. (Mladenović et al., 2007), as well as distribution systems (Teodorović, 2016).

First, by applying the p-median location problem (p = 1), the location of the CDP, i.e. one household that can have this role, within each zone was defined, thus defining the first strategy. Thus, the model was applied to each of the 7 zones. Then, in order to define another strategy, using the same location model, one site was selected for the CDP, with potential sites now being pre-selected sites (medians) within each zone.

It is assumed that households, as potential locations for CDP, have adequate access infrastructure (parking, elevator, etc.), storage space and information and communication systems (which enable communication with suppliers and customers) and voluntarily accept the role of CDP. There is at least one person present in the household in the period from 8 am to 8 pm who can receive or hand over the goods to the customer.

The model is defined as follows (Teodorović, 2007):

Minimize

$$F = \sum_{i}^{n} \sum_{j}^{n} f_i d_{ij} x_{ij} \tag{1}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = 1, \qquad i = 1, 2, \dots, n \tag{2}$$

$$\sum_{j=1}^{n} x_{jj} = 1 \tag{3}$$

$$x_{jj} \geq x_{ij}, \qquad i, j = 1, 2, \dots, n; i \neq j \tag{4}$$

$$x_{ij} \in \{0,1\}, \qquad i, j = 1, 2, \dots, n \tag{5}$$

In the case of the first strategy, i.e. the application of the CDP selection model in each zone, the notation has the following meaning:

n – number of customers in the zone

$x_{ij} = \begin{cases} 1, \text{ if the goods for customer } i \text{ are delivered to user } j \\ 0, \text{ otherwise} \end{cases}$

d_{ij} – distance from customer *i* to customer *j*

f_i –number of customer requests for delivery in the observed period.

Constraint (2) ensures that each customer is served by the CDP, i.e. in the selected household. Constraint (3) indicates that one CDP should be located in the zone. Constraint (4) indicates that customer whose household is selected for CDP receive their orders in their own household. Constraint (5) reflects the binary nature of the variablex_{ij}. In order to solve the set task, data on the number of deliveries to each customer in each zone during 20 days were simulated, according to the uniform distribution U(0,10). The total number of deliveries during this period is 190. These data, together with the distances$d_{ij}$are shown in Table 1. Using the defined model in the Microsoft Excel solver for each zone, the solutions, i.e. CDP locations, shown in Figure 2, were obtained.

Table 1. Distances d_{ij} from customer *i* to customer *j* (in meters) (values taken from the *Google maps* application service)

zone	**zone 1**					**zone 2**					
customer	**1**	**2**	**3**	**4**	**5**	**customer**	**1**	**2**	**3**	**4**	**5**
1	0	160	400	450	400	1	0	1500	2400	2600	2600
2	160	0	230	300	220	2	500	0	350	550	600
3	400	230	0	280	190	3	1000	1900	0	190	210
4	450	300	280	0	130	4	1000	1800	1000	0	140
5	400	220	190	130	0	5	850	1600	900	450	0
num. of requests	3	8	10	8	3	**num. of requests**	8	7	0	7	9
zone	**zone 3**					**zone 4**					
customer	**1**	**2**	**3**	**4**	**5**	**customer**	**1**	**2**	**3**	**4**	**5**
1	0	180	500	350	450	1	0	100	92	2400	3900
2	180	0	300	400	270	2	2200	0	2300	2300	3800
3	400	230	0	350	210	3	2200	9	0	2400	3800
4	550	400	150	0	120	4	1200	1300	1300	0	1600
5	450	270	30	120	0	5	800	900	900	950	0
num. of requests	4	4	7	5	8	**num. of requests**	5	9	2	1	6
zone	**zone 5**					**zone 6**					
customer	**1**	**2**	**3**	**4**	**5**	**customer**	**1**	**2**	**3**	**4**	**5**
1	0	750	350	500	550	1	0	400	300	280	450
2	800	0	500	300	350	2	500	0	600	750	400
3	300	1000	0	750	800	3	650	300	0	450	160
4	600	300	350	0	160	4	850	500	300	0	400
5	450	700	180	500	0	5	800	400	160	550	0
num. of requests	8	2	5	4	7	**num. of requests**	6	3	8	3	5
zone	**zone 7**										
customer	1	2	3	4	5						
1	0	140	280	350	400						
2	750	0	1000	500	700						
3	400	550	0	170	110						
4	250	400	450	0	170						
num. of requests	8	5	6	2	4						

Figure 2. Locations of CDPs in all service zones

An identical model was applied to select the location of one CDP for the entire service area. In this case, the notation used in the model has the following meaning:

n – number of zones,

$$x_{ij} = \begin{cases} 1, \text{ if customers from zone } i \text{ are served in zone } j \\ 0, \text{ otherwise} \end{cases}$$

d_{ij} – the distance from the potential location (median of customers) in zone *i* to the potential location (median of customers) in zone *j*,

f_i – number of delivery requests in the zone *i* in the observed period.

Constraint (2) ensures that customers from each zone are served by the CDP. Constraint (3) provides the selection of one zone in which the CDP will be located. Constraint (4) ensures that goods for customers from the zone in which it is located are also delivered to the CDP. Constraint (5) reflects the binary nature of the variable x_{ij}. Table 2 shows the distances d_{ij} and the number of requests (deliveries) in each zone. By applying the defined model in the solver of Microsoft Excel, the location of the CDP, shown in Figure 3, was obtained.

Table 2. Distances d_{ij} from the potential location in the zone *i* to the potential location in zone *j* (in meters) (values taken from the application service *Google maps*) and the number of requests of zones in the observed period

zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	0	650	400	900	1500	1100	1500
2	1900	0	1700	250	3100	1500	800
3	500	850	0	1100	1700	750	1700
4	1700	2100	1400	0	2900	1200	550
5	1400	1000	1400	1300	0	2200	1900
6	650	1000	400	1300	1800	0	1800
7	2600	2200	2600	2400	2000	2800	0
num. of requests	32	31	28	23	26	25	25

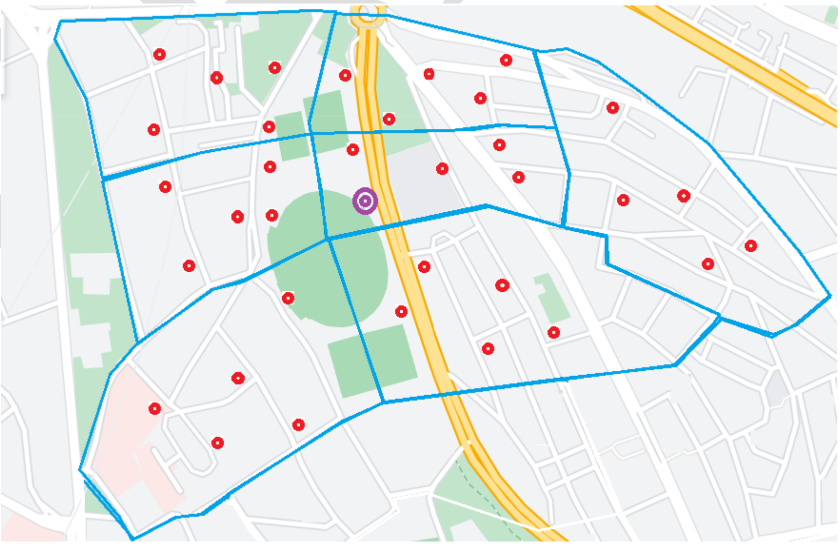

Figure 3. CDP location for the entire service area

The problem can be solved in other ways. Hakimi (1965) proposed a simple algorithm for determining a single median of network:

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}, \ \forall i,j = 1,2,\dots,n, \tag{6}$$

$$v_{ij} = d_{ij} * f_i, \quad \forall i,j = 1,2,\dots,n, \tag{7}$$

$$s_j = \sum_{i=1}^{n} v_{ij}, \quad \forall j = 1,2,\dots,n, \tag{8}$$

$$s^* = \min s_j, \tag{9}$$

Where x_i is the latitude of location of customer i, and $y_i$is longitude of that location.

First, a square matrix of the shortest distances between nodes d_{ij} is formed, where *I* are customers and *j* are the potential locations for the median (6). It is important to note that, unlike the previous model, where the actual distances between customers were used, in this case Euclidean, i.e. distances by "air line" were used. Then, the *i*-th row is multiplied by the number of deliveries for the customer i (7). Summarization is performed on the columns of the newly obtained matrix (8). In this way, the total "weighted" distances s_j from all customers to node *j* where CDP is located are obtained. Node with the minimum of the obtained values (s^*) (9) is median, i.e. CDP location.

Given the large number of nodes, the input data and the procedure for obtaining the solution will not be fully presented, but only the first quadrant of input data (matrix dimensions 5x5), which refers to zone 1, and intermediate results related to this zone will be shown (Table 3).

Table 3. Part of input data and intermediate results of algorithm application

customer	**1**	**2**	**3**	**4**	**5**
x coordinate	44.786901	44.785431	44.786467	44.786695	44.785487
y coordinate	20.460414	20.460468	20.461862	20.46345	20.463141
$\boldsymbol{d_{ij}}$					
customer	**1**	**2**	**3**	**4**	**5**
1	0.00000	0.00147	0.00151	0.00304	0.00307
2	0.00147	0.00000	0.00174	0.00324	0.00267
3	0.00151	0.00174	0.00000	0.00160	0.00161
4	0.00304	0.00324	0.00160	0.00000	0.00125
5	0.00307	0.00267	0.00161	0.00125	0.00000
num. of requests	3	8	10	8	3
$\boldsymbol{v_{ij} = d_{ij} * f_i}$					
customer	**1**	**2**	**3**	**4**	**5**
1	0	0.00441	0.00453	0.00913	0.00922
2	0.01177	0	0.01389	0.02591	0.02139
3	0.01512	0.01737	0	0.01604	0.01611
4	0.02434	0.02591	0.01283	0	0.00998
5	0.00922	0.00802	0.00483	0.00374	0

Vector of total "weighted" distances s_j, starting from the value of the sum of the distances of all customer to customer 1 in zone 1 to the sum of the distances of all customers to customer 5 in zone 7, is [1.2918; 1.1888; 1.0681; 0.9568; 0.8916; 0.8813; 0.8153; 0.9354; 0.9849; 1.1268; 1.1401; 1.0903; 0.9209; 0.8671; 0.8604; 0.7931; 0.7786; 0.7784; 0.8696; 0.9883; 1.3508; 1.3346; 1.5813; 1.737; 1.8563; 1.3954; 0.8959; 1.109; 1.327; 1.1554; 0.856; 0.898; 1.0569; 1.0716; 1.2136]. For the CDP, the household of customer 3 in zone

4 should be chosen, because this node corresponds to a minimum total "weighted" distance, which is 0.7784. The obtained solution is identical to the solution shown in Figure 3, obtained by applying the previously defined model.

4. CONCLUSION

The development of e-commerce also influences the development of different home delivery models. Thus, in recent years, delivery to CDPs has become increasingly important. The introduction of this delivery model aims to reduce flows, the number of engaged workers and vehicles, the number of vehicle deployment, energy consumption and costs, as well as the other economic, social and environmental benefits. CDPs can be a variety of purpose-built or existing facilities in traffic-friendly locations, including customer households.

This paper presents the procedure of locating CDPs, i.e. the selection of the customer household that will perform this function in the area of the City of Belgrade, using the p-median location problem. This achieved the basic goal and contribution of the paper. The paper provides an opportunity for future research. Comparative analysis of delivery parameters (mileage, operating time, vehicle utilization, costs, etc.) before and after the introduction of CDPs, as well as cases of introduction of one or more CDPs, should be the focus of future research to determine the effects of the introduction of these solutions. The possibility of applying the model to a real problem of larger dimensions (a larger number of service zones, customers, deliveries and CDPs) is also one of the directions of future research. In this context, the possibility of applying other problem-solving methods (e.g. heuristic and metaheuristic algorithms) should be explored.

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OPERATIONAL AND REGULATORY ASPECTS OF REPURPOSING AIRCRAFT PASSENGER CABIN FOR TRANSPORT OF CARGO

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Abstract: *COVID-19 reduced demand for passenger flights but boosted air freight demand due to the need for timely delivery of critical products such as pharmaceuticals, medical supplies and personal protective equipment and other products that are vital to the functioning of sensitive supply chains. Therefore, one of the consequences of the outbreak of the COVID-19 pandemic is the global lack of air cargo capacity and the consequent increase in passenger-to-freighter conversions and use of aircraft passenger cabins for cargo loading, which allows air carriers an essential source of revenue as demand for passengers remained declining due to travel restrictions related to Covid-19 and ruined passenger revenues. This paper provides insight into current regulatory requirements, risk assessment and guidelines for best operational practice regarding the transport of cargo on the main deck of passenger aircraft. Operational and regulatory aspects for P2F conversion that needs to be approved by the state aircraft registration to ensure an acceptable level of safety, regardless of whether the seats and other passenger service provisions are completely removed or not, are elaborated in the paper.*

Keywords*: conversion of aircraft passenger cabin, air cargo demand, COVID-19 pandemic, safety risk assessment*

1. INTRODUCTION

The COVID-19 pandemic severely and unprecedentedly set back the business of airlines, airports, and air navigation service providers. It has caused a sharp and sudden drop in air traffic, and the air transport industry is one of the hardest hit industries in this context, with the uncertain prospects for its return to pre-COVID-19 levels (Albers and Rundshagen, 2020). The air cargo sector has suffered comparatively less than the passenger sector, which is more sensitive to external influences (Li, 2020, Sun et al., 2021). Wang et al. (2021) have found that GDP and inflation directly influence passenger and cargo volume, while fuel prices directly influence only cargo volume with the cargo network being less sensitive to GDP and inflation changes than the passenger network. With the collapse of passenger air travel demand due to the coronavirus crisis and the closure of borders, many carriers have cancelled most of their routes, leaving passenger

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planes grounded at airports around the world. This caused a significant reduction in cargo capacity for the part that belonged to the belly of passenger aircraft.

The pandemic has forced some airlines to modify their passenger aircraft to make room for cargo in their passenger compartments, in addition to their cargo holds. Among first to do so were Lufthansa which removed seats from four of its A330s for cargo carriage, Finnair which modified two Airbus A330 for cargo use and Air Canada which reconfigured the cabins of three of its Boeing 777aircraft to make extra space for cargo.

Since passenger aircraft are not certified to carry cargo in the passenger cabin, any aircraft reconfiguration in this manner requires a formal authorisation from the national aviation authority (NAA) of the State of the Operator as well as thorough evaluation of cargo limitations to ensure that structural loads meet design limits.

The paper clarifies regulatory and operational requirements for the:

1. transport of cargo in existing approved cabin areas,
2. transport of medical supply on passengers' seats,
3. transport of non-medical supply cargo on passengers' seats,
4. transport of cargo after seat removal.

2. THE IMPACT OF COVID-19 PANDEMIC ON AIR CARGO TRAFFIC OUTCOMES

After decades of continued growth in global passenger traffic, the pandemic has halted almost all air traffic operations in the second quarter of 2020. As a result, the total number of passengers for the year has dropped dramatically from 2019, to levels recorded in the 1990s. As for cargo traffic, it started to recover rapidly around May 2020 when lockdowns began to ease, leading to a V-shaped recovery for the rest of the year. At the end of the year, global air cargo traffic measured in revenue tonne-kilometres had returned close to pre-crisis values.

The International Air Transport Association (IATA) data for global air freight markets (IATA, 2022) shows that full-year demand for air cargo increased 6.9% in 2021, compared with 2019 (pre-covid levels) and 18.7% compared with 2020. Regional differences in international air cargo performance in 2021 compared to 2019 are shown in table 1. North American, Middle East and African carriers were the strongest performers, Asia-Pacific and European carriers recorded small rise while Latin American carriers were the only ones to record a decrease.

Table 1. International air cargo developments (% change 2021 vs. 2019)

	RCTK* (% Change)	**ACTK* (% Change)**
Total market	**7.6**	**-19.4**
Africa	11.3	-14.6
Asia Pacific	3.6	-17.1
Europe	3.6	-17.4
Latin America	-15.2	-30.2
Middle East	10.6	-10.1
North America	20.2	0.2
* RCTK: revenue cargo tonne-kilometres ACTK: available cargo tonne-kilometres		

At the same time, global passenger traffic fell by 58.4% in 2021 compared to the full year of 2019. This represented an improvement compared to 2020, when full year revenue passenger kilometres were down 65.8% versus 2019. International passenger demand in 2021 was 75.5% below 2019 levels, while domestic demand in 2021 was down 28.2% compared to 2019. Capacity in 2021 was 65.3% and 9.3% lower than in 2019 for international and domestic travel respectively.

Figure 1 (IATA, 2022b) illustrates the different traffic results on key international passenger and freight routes in 2021. The recovery of passenger traffic was much slower than the recovery of cargo traffic, with significant differences on routes.

Routes to, from and especially within Asia experienced the largest decrease in 2021 mainly because of the policy of strict border closures pursued by the Asia-Pacific governments. On the other hand, traffic on routes that were subjected to more relaxed travel recovered much faster, especially tourism-intensive North and Central America.

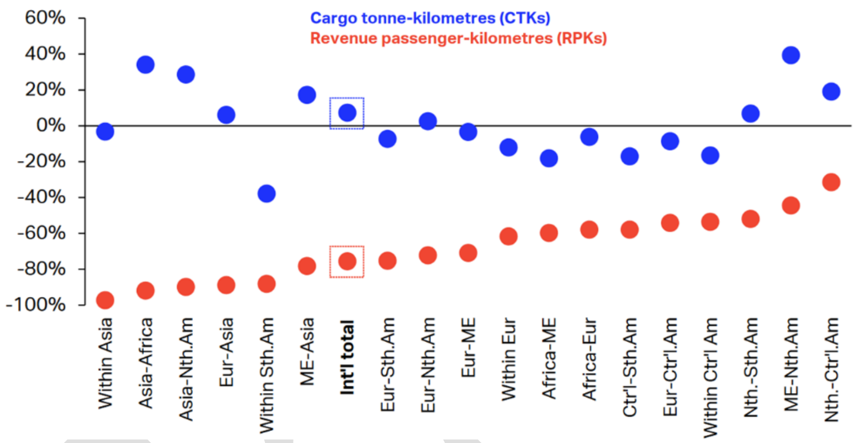
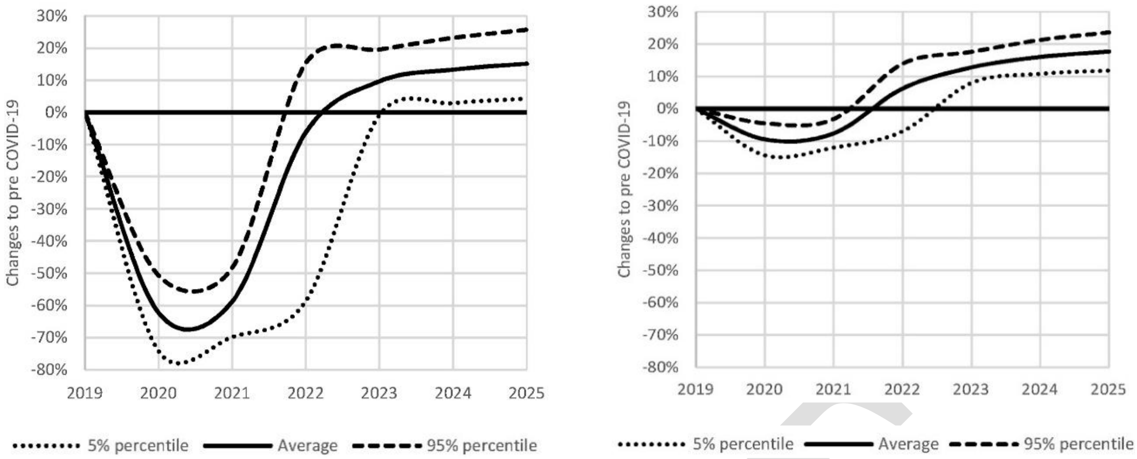


Figure 1. International CTKs and RPKs, % change 2021 vs. 2019

As for the cargo traffic, traffic results were varying across key international markets. Middle East-North America, Asia-Africa and Asia-North America routes increased by almost one third versus 2019. However, some markets showed a significant decline, for example within South America it amounted for 38%. The differences can be at least in part attributed to the availability of dedicated freighters. Routes with a high share of cargo capacity on belly-hold aircraft capacity of passenger aircraft have been left without that capacity due to the cancellation of international wide-body passenger flights.

Gudmundsson et al. (2021) predicted that the cargo sector in Europe and the Asia Pacific will recover in about 2.2 years, and in North America in about 1.5 years. Figure 2 (Gudmundsson et al., 2021) highlights the difference between passengers (a) and freight (b) in terms of average recovery time and the 5th and 95th percentile confidence levels.

Evidently, there is a longer duration of the decline in passenger than cargo traffic. The reduction in the number of passengers in air transport averages about 60% compared to 10% for cargo. Overall, the simulation analysis indicates that air transport recovery will take on average 2.4 for passengers and 2.2 years for freight. Despite faster recovery of freight than passenger transport, passenger transport appears to be recovering more strongly after major economic shocks.



(a) - World Passengers (b) - World Freight

Figure 2. Distribution of recovery times for air passenger and air freight

3. WAYS OF INCREASING AIR CARGO CAPACITY DURING THE PANDEMIC

Since the COVID-19 pandemic caused the sharp decrease in passenger travel, many airlines turned to transport of freight to provide alternative revenues and reduce losses. Prior the pandemic, most of the world's air cargo was normally transported in the belly of passenger planes rather than the cargo aircraft, rising as high as 80% on transatlantic routes (Thorn, 2020). With the cancellation of many passenger flights and the consequent loss of their belly hold capacity, existing dedicated freighter aircraft were insufficient to meet demand, and the price for air cargo increased.

Moreover, re-opening of supply chains in late February 2020 was accompanied with a strong impact on airfreight rates due to lack of belly hold space. TAC Index figures from March 17, 2020, show that average airfreight rates on services from Shanghai to the US increased by 29.7% on the prior week to reach \$4.71 per kg. On services from Shanghai to Europe there was a 17.7% week on week increase to \$3.19 per kg (Brett, 2021).

Aircraft operators considered two possible solutions:

1. to convert passenger to freight aircraft, or
2. to carry cargo in the main cabins of passenger aircraft.

Converting passenger into cargo aircraft is a complex engineering process, and every aircraft and aircraft type is unique. It can take several months and involves the elements shown in Table 2 (Spells and Tan, 2022).

Table 2. Main elements of passenger to freight aircraft conversion process

CONVERSION ELEMENT	DESCRIPTION
Removal out of the cabin	Galleys, seats, overhead lockers, toilets, in-flight entertainment facilities, etc....
New loading door	The door is usually cut at the front of the fuselage, after which new reinforced frames are installed.
New higher strength cabin floor	Reinforced floor that is strong enough to withstand cargo loads and ensure the maximum utilisation of the floor space is installed.
Testing	A series of tests, and inspections are required throughout the conversion process prior to certification.

Boeing's World Air Cargo Forecast released in November 2020 covering the 2020-2039 period predicts the cargo market will grow at an annual rate of 4 percent over the next 20 years, demanding 60 percent larger freighter fleet. Boeing predicts than one-third of these deliveries will be new widebody freighters while nearly two-thirds of the deliveries (1,980 aircraft) will be conversions, 72 percent of which will be 737-sized freighters (Boeing, 2020b).

The demand for passenger-to-freighter conversions, previously largely driven by the need of express parcel carriers to expand their fleets of smaller freighters was increased by the pandemic. However, it is time consuming and very expensive process. Longney and Standen (2022) in the Reed Smith's report titled Global Air Freight's Future, cited IBA data to say a narrowbody conversion could cost about $4.2 million for a 737-800 and $6.1 million for an A321-200. A widebody conversion could cost $14.7 million for a 767-300ER and $18.4 million for an A330-300.

All the above has led to the launch of so called *preighter's flights* to make up for the shortfall in belly hold capacity. Many airline operators begun to modify their passenger aircraft to transport cargo on passenger seats or even stowed on cabin floor after removing passenger seats. Moreover, to fit and transport as much cargo as possible, they have removed passenger "luxuries" (inflight entertainment facilities, and even some of the catering facilities) out of their cabins (Soni, 2022). Preighters have played important role on some markets, for example more than one fifth of cargo was carried by preighters on top Middle East routes as shown in the Figure 3 (IATA, 2021).

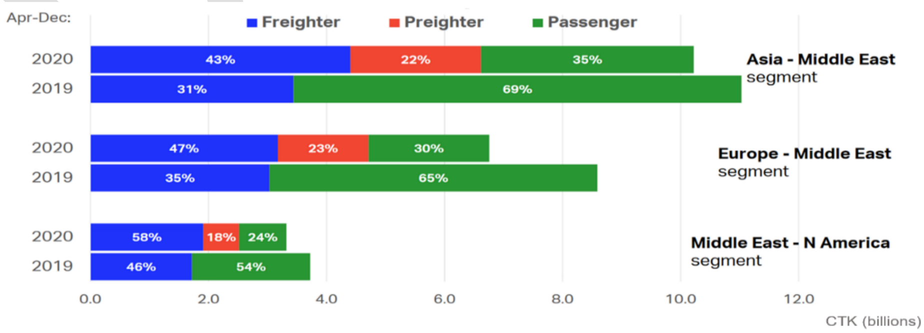


Figure 3. Scheduled cargo tonne-kilometres by type of operation

According to Cirium (Mellon et al., 2021) 200 aircraft were reconfigured to preighters until May 2021. The largest part refers to wide-body aircraft (81.5%), among them 63 Airbus A330 and 68 Boeing 777.

4. TRANSPORT OF CARGO IN THE AIRCRAFT PASSENGER CABIN

Since passenger aircraft are not certified to carry cargo in the passenger cabin, any aircraft reconfiguration in this manner requires a formal authorisation from the national aviation authority (NAA) of the State of the operator as well as thorough evaluation of cargo limitations to ensure that structural loads meet design limits.

Aviation authorities of different countries and main professional air transport organisations have prepared and published guidelines and technical instructions to support and help airlines with the repurposing of aircraft passenger cabin for the transport of cargo. Also, aircraft manufacturers and design approval holders such as Airbus and Boeing have published specific guidelines to support the repurposing of aircraft passenger cabin for the transport of cargo (Boeing, 2020a and Airbus, 2020).

4.1. Regulatory requirements

There are many potential problems that arise in the air transport of cargo and mail, especially in the passenger cabin of aircraft, and the current regulations are dynamic and inconsistent in terms of testing and quarantine. For example, a 14-day quarantine at the destination not only for the entire crew, but also for cargo implied 14-day delay and posed serious problem for airline operations. Because of this unsustainable situation, airlines have been vigorously lobbying and asking governments to allow exemptions from these regulations, such as exempting flight crew who do not communicate with the public from quarantine rules.

Loading of verified cargo and mail in the cabin of passenger aircraft is permitted subject to defined conditions and specific regulator authorisation. According to ICAO (International Civil Aviation Organisation) Annex 8, the repurposing of a passenger aircraft not certified for the transport of cargo needs to be approved by the State of aircraft registry to ensure the continuing airworthiness of the aircraft after modification. Cargo loaded in the passenger cabin must not include any dangerous goods or live animals. The passenger cabin should be considered as a Class A cargo compartment, i.e., one in which the presence of a fire would be easily detected by a crew member and each part of the compartment is easily accessible in flight (ICAO, 2021). ICAO has provided information (ICAO, 2020) on the guidelines published by ICAO Member States and other organisations concerning the transportation of cargo in a cabin certified to carry passengers and conditions for the issuance of an exception/exemption to operators.

Basic regulations relating to the carriage of cargo in the passenger compartments of aircraft are contained in:

a) Regulation (EU) No 965/2012, CAT.OP.MPA.160 Stowage of baggage and cargo (Commission Regulation (EU), 2012)
b) FAA (US Federal Aviation Administration): Title 14 Code of Federal Regulation (14 CFR) part 121 (FAA, 2022).
c) According to CAT.OP.MPA.160 operator shall establish procedures to ensure that:
d) only hand baggage that can be adequately and securely stowed is taken into the passenger compartment; and

e) all baggage and cargo on board that might cause injury or damage, or obstruct aisles and exits if displaced, is stowed to prevent movement (Commission Regulation (EU), 2012).

Following the decline in air traffic caused by the COVID-19 pandemic, airlines urged IATA to produce instructions on how to use passenger cabins in the aircraft for safe transport of cargo. IATA has issued Guidance for the transport of cargo and mail on aircraft configured for the carriage of passengers (IATA, 2020) with detailed instructions for airlines and a prescribed risk assessment procedure. The IATA guidelines emphasize the importance of interested operators being familiar with cargo transport before even considering carrying cargo in aircraft passenger cabin. Also, a detailed risk assessment to identify hazards and mitigate possible risks is strongly recommended. Most common hazards and consequences in the worst-case scenario, risks and mitigation actions are detailed in these guidelines. Table 3 (IATA, 2020) shows the possible cargo configurations for diverse types of cargo.

Table 3. Applicable cargo configurations with regards to the type of cargo

Cargo Type	**Passenger cabin**					**Cargo CMPRT**
	Overhead bin/coat cupboard	**Under seat**	**On the seats** In cargo seat bags	With nets/straps	**On the cabin floor** (no seats, with nets/ straps)	
Humanitarian supplies/Medicines	YES	YES	A	A	A+C	YES
General cargo	YES	YES	A	A	A+C	A
Dangerous Goods	NO	NO	NO	NO	NO	B
CAO DG*	NO	NO	NO	NO	NO	D

**Cargo Aircraft Only Dangerous Goods*

A: *require NAA (national aviation authority) approval;* B: *operators holding a NAA approval to carry dangerous goods as cargo;* C: *require acceptance by aircraft manufacturer;* D: *operators holding a NAA approval to carry dangerous goods. CAO dangerous goods must be loaded into a Class C cargo compartment (no passengers on the aircraft)*

Very soon, EASA (European Union Aviation Safety Agency) has issued Guidelines for the Transport of Cargo in Passenger Compartment, as a special exemption in terms of Regulation (EU) 2018/1139 of the European Parliament and of the Council, pursuant to which operators are required to request time-limited airworthiness approval for an aircraft whose configuration does not meet the classifications prescribed for cargo transport. For transport of cargo other than medical supplies as well as in case of seats' removal, a STC (Supplemental Type Certificate) application is required and promised to be processed by EASA with priority (EASA, 2020).

In case of transporting medical supplies provided they are not classified as dangerous goods and after having demonstrated an urgent need, an operator may exceptionally consider applying for an exemption pursuant Article 71 of the Regulation (EU) 2018/1139 (EASA, 2022). Exceptionally, national regulators may also grant approval for aircraft that do not have the necessary modifications to enable the transportation of supplies essential for COVID-19 response (Vasilj et al., 2021). US Federal Aviation Administration (FAA) also gave a one-year approval for the transport of goods in the passenger cabin (FAA, 2021).

According to current regulations, verified cargo may be carried in:

– Approved locations within the passenger cabin: overhead stowage bins, closets not dedicated to emergency equipment, floor mounted stowage (e.g., doghouses) and under seat stowage areas,

– Non-approved locations within the passenger cabin: passenger seats and passenger cabin floor (seats removed).

If cargo is carried in approved locations within the passenger cabin no additional approval is needed, but the following restrictions and rules must still be applied (IATA, 2020):

a. The volume and the mass of cargo shall not exceed stowage maximum capacity and the structural loading limits of the floor or seats prescribed in the manufacturer's Weight and Balance Manual;

b. Cargo should be stowed only in a location that enable its restraining. Restraint devices and their attachment points shall restrain the cargo in accordance with applicable certification specifications;

c. The loading of the cargo under the seat place should not exceed 9 kg (20 lbs). The seat must be equipped with a restraint bar system to prevent forward and sideward movement and the cargo placed fully underneath the seat;

d. Items stowed in lavatories or against bulkheads should be restrained against any movement and the bulkheads should carry a label stating the maximum capacity;

e. Cargo should be located where it will not impede access to emergency equipment or hinder egress in case of an emergency evacuation;

f. Dimensions of cargo items placed in enclosed stowage areas shall enable latched doors to be closed securely;

g. Checks should be made before take-off, before landing and whenever the fasten seat belt signs are illuminated and under orders of pilot in command to ensure that cargo is properly stowed.

When transporting cargo in non-approved locations operators should obtain prior approval from their NAA, which may require the issuance of a STC (supplemental type certificate). For carriage of cargo on passenger seats, the following limitations are to be considered (IATA, 2020):

a. Mass of cargo loaded on the seats must be within the certification limits of the seat (typically, it amounts 77 kg/170 lbs) and should be evenly distributed across the seat row;

b. Actual weight of cargo and even load distribution shall be in accordance with the limitations in the aircraft flight manual (AFM), aircraft Weight and Balance Manual and minimum flight weight limits;

c. Flight envelope used for regular passenger flights shall be applied; alternatively, curtailments can be re-assessed but only within applicable parameter limitations;

d. The number and type of restraint devices and their attachment points shall ensure adequate restraining the cargo in accordance with applicable certification requirements;

e. Vertical centre of gravity (CG) of the cargo should be equal to or lower than the passenger CG shown in the envelope drawing of the seats in use;
f. Mass of cargo should be appropriately accounted for in the weight and balance system and any aircraft operational limit is respected.

Operator may opt to remove passenger seats and load cargo on the passenger cabin floor. In this case the cargo restraints are connected directly to the seat tracks and the following restrictions are to be applied (IATA, 2020):

a. One complete row of seats at both ends of the tie down area should be unoccupied (free of passengers and cargo);
b. Maximum cargo weight for any given tie down scenario is recommended by the aircraft manufacturer and should be respected;
c. Cargo should be evenly distributed across the tie down area and shall not exceed the area load limits recommended by manufacturer or the floor limits defined in the weight and balance manual;
d. The cargo CG height as well as the lateral and longitudinal CG of the cargo shall not exceed the value provided by the aircraft manufacturer;
e. Cargo shall not extend or overhang into the aisles, doorways and galleys and shall not be loaded in exit rows;
f. Cargo must be adequately restrained to avoid movement during flight or emergency landing conditions;
g. Nets used to restrain cargo items should be TSO/ETSO (FAA Technical Standard Order/EASA European Technical Standard Order) approved and any load limitations of these nets including their attachment means should be adhered to. Any deformation of these nets should be assessed for contact with other facilities in the cabin and be demonstrated not to block emergency evacuation exits nor access to emergency equipment.
h. The maximum weights that can be restrained as per forward, aft, lateral and vertical limits shall remain within the limits specified by the aircraft manufacturer;
i. The number of tie down points for a given weight and type of cargo, number of stud tie down fittings and strap assemblies should be applied according to aircraft manufacturer's recommendation. TSO certified nets and straps should be used;
j. Attention must be given to avoid load share of restrained cargo into any galleys, lavatories, partitions, or other fixed structures.

4.2. Operational aspects

Operators should select cargo that is going to be loaded in the passenger cabin on the basis of suitability for manual handling and loading and availability of restraint devices bearing in mind the following (IATA, 2020):

a. The content of cargo items should be verified to ensure that there are no dangerous goods, especially if dealing with medical supplies which might be classified as dangerous goods, moreover, wet cargo should not be loaded;

b. The weight of individual packages should be such as to minimise injury during manual handling and they should be free of sharp edges;

a. The volume of packages should comply with the dimensions of overhead bins, coat cupboards or under the seats space; Weight of the packages should comply with load limitations of available bins, bags, etc.;

b. The weight distribution throughout the aircraft should be in accordance with the load master's instructions;

c. CG of the cargo should be equal to or lower than the CG height recommended by the aircraft manufacturer;

d. Availability of loading, unloading, shoring, load spreading and restraint equipment should be considered.

For carriage of cargo in non-approved locations the operator should also consider the loading limitations and restraint capability of the seats or floor. To identify the cargo that is going to be loaded in passenger cabin the special handling code "CIC" (cargo loaded in passenger cabin) should be used to facilitate resource planning for loading/ unloading, load preparation and load control.

Since most of the departure control systems (DCS) are set to calculate the passenger weights only, appropriate solutions for allocating "extra" weight in each cabin section should be investigated and applied to avoid CG error in final calculation. While planning the stowage of cargo items, care should be taken to ensure that the cabin depressurization relief vents shall remain unobstructed. Also, Loading Instruction Report forms do not include the passenger compartment so all relevant information should be given in the "Special instructions" box. These reports should contain detailed instruction on load quantity and maximum loads per each cabin section, overhead bin and coat cupboard as well as loading/unloading sequence.

Equipment that is used to access aircraft passenger cabin doors is not intended to be used for cargo loading. Elevating equipment, typically used for boarding and loading PRM passengers or catering, may be used for cargo loading. safely through the passenger door. When using passenger stairs to load cargo into the cabin, it is recommended to evenly distribute loading personnel on the stairs and move the packages from the ramp upwards by passing the packages from one person to the next.

When cargo is to be loaded in passenger cabin with seats installed, in addition to the above considerations, the following should be considered (IATA, 2020):

a. Covering all seats with a protective material;

b. All aisles, and access to emergency equipment shall always remain unobstructed;

c. For widebody aircraft, cargo must be loaded cargo must be loaded in such a way as to provide for each section ca of the cabin a means to cross from one aisle to the other (for example, an empty seat row);

d. The cargo load shall not exceed the maximum height of the passenger seat in the fully upright position;

e. Seatbacks should be in the upright position and seat belts behind the seat cushions;

f. The inner arm rests should be folded if possible;

g. Cargo in each seat row should be secured with straps, rope or nets;
h. Heavier boxes should be loaded as low as possible to keep the vertical CG within the limits and towards the centroid to limit the horizontal CG shift;
i. The load should be distributed in such a manner to reduce the lateral load imbalance
j. If cargo is carried in cargo seat bags installation instructions provided by manufacturer should be followed.

Moreover, IATA strongly recommends the use of qualified cabin crew familiarized with the correct methods of restraint and trained on cabin fire watch/fighting activities to accompany cargo operations in the passenger cabin.

5. CONCLUSION

Very soon after the outbreak of the COVID-19 pandemic, airlines began to find ways to meet increased demand for air cargo operations and cope with the logistical challenges related to COVID-19 while cargo capacity was significantly contracted due to the suspension of passenger aircraft flights that accounted for about half of the world's cargo transported in the belly holds of passenger aircraft.

Thus, they began to assess the possibility of converting aircraft passenger cabins into a space for safe transport of cargo and/or mail to increase cargo capacity. Aircraft that were converted to carry cargo on the main deck were mostly wide-bodied and they accounted for more than one fifth of cargo traffic on some top Middle East routes. Regulatory requirements differ depending on whether the cargo is carried in existing approved cabin areas or on passengers' seats or stowed on the cabin floor after seats being removed. In the first case, no approval is required, while other situations require appropriate airworthiness approvals from the State of registry. Only exemptions could be granted for the carriage of medical supplies on passengers' seats.

There are many considerations to be made when loading cargo into the passenger cabin and carriers should comply with the effective regulations of the competent authorities as well as adhere to IATA guidelines and instructions of the aircraft manufacturers. When passenger cabin is used for transport of cargo the following goals are identified as most important: timely fire protection and suppression, restraining of cargo to avoid its movement and changes of aircraft centre of gravity during all flight phases and emergency landing conditions, complying of cargo mass and volume with maximum capacity limitations and structural loading limits of the aircraft and all its stowing areas. Sufficient and qualified cabin crew to accompany cargo operations and monitor all areas of the passenger cabin during the flight and address any possible risk of fire, leakage or other unforeseen circumstances that may occur in the aircraft passenger cabin during the flight should be engaged.

The COVID-19 pandemic has severely disrupted the air cargo industry, but cargo markets have recovered to pre pandemic levels with significant differences among regions testifying the vital role of air cargo in delivering critical products like medical supplies and personal protective equipment as well as enabling e-commerce during the lockdown periods. The COVID-19 pandemic has led airlines to see the possibility of using their transport capacities differently and generate revenue in a way that has been unusual so far.

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ROAD FREIGHT TRANSPORT SECTOR IN SLOVENIA AND ITS CONTRIBUTION TO THE MACROECONOMIC INDICATORS AS COMPARED TO EU AVERAGES

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Abstract: *Transport has a linking function between all economic activities, enabling their existence and development. At the same time, it is an economic sector that generates a significant part of the national income and directly or indirectly employs a large part of the labor force. Road transport is crucial for the development of the European economy and society, and despite the recommendations of the European transport policy, the volume of road transport is increasing, both in terms of passenger and freight traffic. The authors focus on the extent to which road freight transport sector in Slovenia contributes to GDP and employability, comparing Slovenia's results with the European average. Finally, they attempt to estimate the loss in selected macroeconomic indicators in Slovenia due to the involvement of foreign carriers in the provision of transport services related to the Slovenian economy.*

Keywords*: road freight transport, macroeconomic indicators, Slovenia, EU, shift-share analysis*

1. INTRODUCTION

Transport, whether passenger or freight, is a critical factor in the development and existence of modern economies and societies. Transport has a linking function between all economic activities, enabling their existence and development. At the same time, it is an economic sector that generates a significant part of the national income and directly or indirectly employs a large part of the labor force.

The volume of traffic flows, including the volume of freight flows has increased in recent decades, and the rough forecast for the EU is that there will be about 60% more freight flows in 2050 than in 2010 (Krause, et al., 2020), despite the long-standing tendency in the EU to decouple transport flows from economic development. Most of this growth will be by road, and the question is which carriers will benefit most from it as in recent years, we have seen carriers operating throughout the EU, regardless of whether freight flows are in any way linked to the economies of the countries from which they originate.

In the article, the authors focus on the extent to which the road freight sector in Slovenia contributes to GDP and employability, comparing Slovenia's results with European averages. In the second phase, they attempt to estimate the loss of selected macroeconomic indicators in Slovenia due to the involvement of foreign carriers in the provision of transport services related to the Slovenian economy.

The paper is divided into five sections. The introduction in section one is followed by a brief theoretical background on freight flows prediction and an overview of road freight transport in the EU. Section three describes the data and methodology used to conduct the study, while section four is the core of the paper and includes the analysis of the Slovenian and the EU road freight sector and its macroeconomic impact. Section five is devoted to the conclusions.

2. BACKGROUND

The studies show that freight flows respond quickly to economic and political changes, with road transport being the most responsive mode. The relationship between the volume of freight flows and the volume of economic activity has long been a method for predicting future flows of goods. As early as 1962, Tinbergen established a gravity model that predicted the flow of goods between two countries based on their GDP and the distance between them. In the following decades, a number of studies have demonstrated a strong correlation between GDP growth and the volume of freight flows, measured in ton kilometers (Brunel, 2005; van de Riet, de Jong, & Walker, 2007). However, some authors point out that forecasting freight flows is challenging and should not be based on GDP data alone (McKinnon in Woodburn, 1996). Instead, the volume of freight flows is related to demographic change, economic structure, transportation costs, globalization of the economy, environmental awareness, logistics concepts used, and characteristics of potential modes (Koorey et al. al, 2000; Holguin-Veras et al., 2011; Meersman & Van de Voorde, 2013).

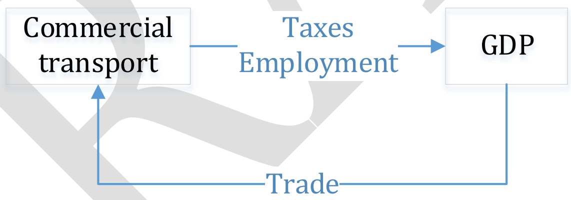


Figure 1: Relation between commercial transport services and GDP

In, 2019, European road freight operators transported about 13.5 billion tons of cargo, covering nearly 160 billion kilometers. The majority of this was provided by German, French, Spanish and Polish carriers (Eurostat, 2022a). These ratios are changing as the international road freight transport in the European Union (EU) is fully open to competition, while domestic transport remains fairly well protected. As a result, cabotage accounts for only a small part of domestic transport in EU Member States; most cabotage takes place in Germany, and almost half of total cabotage in EU is carried out by carriers from Poland. The overall average in Member States is that cabotage accounted for 4.9% of national road haulage for hire or reward in 2020 (Eurostat, 2021).

3. DATA AND METHODS

The key research question of this study was: "Does road freight transport sector in Slovenia contribute to macroeconomic indicators in line with EU averages?".

To answer this question, we used different data from Statistical Office of the Republic of Slovenia, and Structural Business Statistics data from Eurostat.

First, we provided a general overview of road freight sector in EU-27, to determine the competitive position of Slovenian carriers. For this purpose, we first calculated the Herfindahl-Hirschman Index (HHI), then provided the shift share analysis and calculated the market instability index.

HHI is used to determine to determine market concentration, while shift-share analysis was originally a technique for analyzing a region's economic growth patterns, but, we have used it to examine changes in the road freight transport sector in European countries, using number of employed people* as the economic variable studied.

$$HHI = 10,000 \times \sum_{i=1}^{n} s_i^2 \qquad \textbf{(1)}$$

where *s* is the percent market share (of each country *i* in our case).

HHI ranges from close to 0 to 10,000. A market with the HHI of less than 1,500 is considered a competitive, with the HHI from 1,500 to 2,500 moderately concentrated, and with HHI 2,500 or greater is considered highly concentrated market.

Shift-share analysis helps understand changes in market by decomposing them into two parts, where *share* reflects the expected growth (in our case of employment in road freight sector) to maintain the market share, and *shift* reflects the number of employees that a country got or lost in relation to expected growth. Shift-share analysis does not explain causes for economic changes.

$$share_{i,t} = AGR_t \times Q_{i,t-1} = \left(Q_t - Q_{t-1}\right) \times s_{i,t-1} \qquad (2)$$

where *AGR* is annual growth rate (of total) observed variable, *Q* denotes sum of the quantity observed, *i* denotes the single observation (country), while *t* and *t-1* denote the time of observation.

$$shift_{i,t} = \left(s_{i,t} - s_{i,t-1}\right) \times Q_t = Q_{i,t} - Q_{i,t-1} - share_{i,t} \qquad (3)$$

The same data can be used to calculate absolute market share instability (AMSI), which is the measure of market mobility.

$$AMSI = \sum_{i=1}^{n} \left| s_{i,t} - s_{i,t-1} \right| = \frac{\sum_{i=1}^{n} \left| shift_i \right|}{Q_t} \qquad (4)$$

At the end we created a linear regression model to predict production value of Slovenian road freight transport sector.

* Number of persons employed refers to the total number of persons who work in the observation unit (employees receiving remuneration, working proprietors and unpaid family workers) as well as outside working persons who belong to the unit and are paid by it. It includes all persons who are on the payroll of the enterprise, whether they are temporarily absent (excluding long-term absences), part-time, seasonal or home workers, apprentices, etc. (OECD, 2003)

4. THE MACROECONOMIC IMPACTS OF ROAD FREIGHT TRANSPORT SECTOR IN SLOVENIA

4.1. EU road freight transport sector

The transport and storage industry directly employs around 11 million people in EU-27 and accounts for about 5% of GDP (EC, 2017). In 2019, there were 1.25 million companies operating in the transport and storage sector in the EU-27, most of them, more than 540 thousand, in road freight transport. Road freight sector alone employs around 3.3 million workers, which is around 1.7% of total employment of people aged from 15 to 64 in EU-27 (Eurostat, 2022b; Eurostat, 2022c).

The five largest European countries employ just over 60% of all workers in the road freight sector in EU-27;however, the Herfindahl-Hirschman Index (HHI), which is the index of market concentration, has the value of about 950 and shows that the market is rather competitive.

In the Table 1 we present the results of the shift-share analysis.

Table 1: Shift share analysis of road freight sector in Europe for the period from 2016 to 2016

State	Share	Shift	Total	State	Share	Shift	Total	State	Share	Shift	Total
Belgium	6,949	-3,049	3,900	**France**	41,691	-11,091	30,600	**Netherlands**	14,049	-3,378	10,671
Bulgaria	8,283	-3,245	5,038	**Croatia**	2,658	1,235	3,893	**Austria**	7,343	-6,100	1,243
Czechia	15,093	-9,397	5,696	**Italy**	38,558	-10,382	28,176	**Poland**	42,941	80,418	123,359
Denmark	3,457	-2,182	1,275	**Cyprus**	224	98	322	**Portugal**	8,051	703	8,754
Germany	50,009	-26,369	23,640	**Latvia**	3,044	-2,192	852	**Romania**	17,615	-1,429	16,186
Estonia	1,919	-1,401	518	**Lithuania**	7,639	22,774	30,413	**Slovenia**	2,870	2,656	5,526
Ireland	2,546	657	3,203	**Luxembourg**	876	-476	400	**Slovakia**	5,478	1,349	6,827
Greece	4,283	-2,856	1,427	**Hungary**	9,196	-1,798	7,398	**Finland**	5,293	-5,997	- 704
Spain	38,274	-9,987	28,287	**Malta**	129	36	165	**Sweden**	9,459	-8,596	863

Source: Authors, based on (Eurostat, 2022b)

As said, shift-share analysis does not directly explain causes for economic changes, nevertheless, many of countries showing strong competitive effect (shift) on the employment in road freight sector, also have (relatively) low salaries in road freight sector (in comparison to EU-27 average) or (relatively) low share of personnel costs in total purchases of goods and services, and vice versa.

4.2. The road freight sector in Slovenia

As we could see in Table 1, road freight transport sector in Slovenia is competitive, but compared to others, the Slovenian transport sector is relatively small, so it does not have as big an impact on the European transport market as the fast-growing road transport sectors of Lithuania and Poland.

According to Slovenian Statistical Office (SURS, 2022) and Eurostat (2022b) there are about 5,700 trucking companies in Slovenia, which together employ around 29,300 people or around 3.0% of all employed people in Slovenia. Although the share of people employed in road freight sector in Slovenia is higher than the average in EU is, Slovenian transport companies are still relatively small, employing on average 5.1 people (only 3.6 until 2010), while the current average on European level is 5.9. On the other hand, the production value of road freight transport in Slovenia as compared to Slovenian GDP was around 6.4% in 2019, while the EU-27 average stopped at 2.3%; interestingly two most prominent countries in European road freight transport sector had similar numbers to Slovenia, in particular Poland with 6.4% in 2019 and 5.5% in 2016, while Lithuania is registering record numbers with 13.3% in 2019, a significant growth from 9.5% in 2016. Also, the gross operating rate, which is the measure of profitability that provides the ratio between gross operating surplus* and turnover† is relatively high in Slovenia (12.7%), higher than EU-27 average (10.6%), which indicates that the Slovenian trucking companies are efficient in their operation and are good at turning sales into profits.

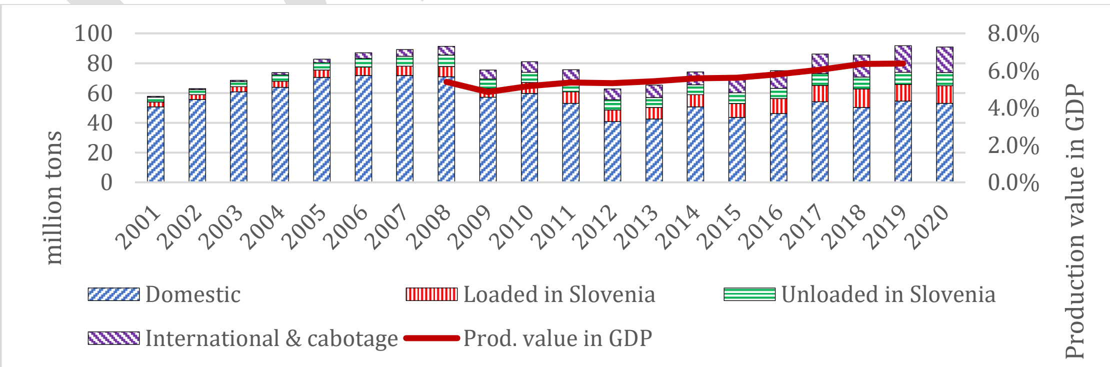
Slovenia has an open economy; in 2020, Slovenia exported 17.6 and imported 20.8 million tons of goods. As shown in Table 2, Slovenia conducts most of its trade with neighboring countries. The five most important trading partners account for almost 75% of exports (around 13.2. million tons) and 58% of imports (12.1 million tons).

Table 2: Slovenia's main trading partners

Export (tons)		Import (tons)	
Country	**Volume**	**Country**	**Volume**
Italy	6,268,386	Austria	3,599,182
Austria	2,324,830	Italy	3,038,646
Croatia	2,201,896	Croatia	2,866,629
Germany	1,607,177	Germany	1,401,812
Hungary	751,478	Hungary	1,101,110
All partners	**17.560.899**	**All partners**	**20.821.848**

Source: Authors, based on (SiStat, 2022)

Slovenian road freight carriers have achieved record figures from 2007 and 2008 in recent years, but in the following figure (Figure 2) we can see that the work structure of Slovenian road freight carriers has changed; there is less domestic transport and more integration with foreign markets. If we look at Table 2, we can assume that most trade flows with Austria, Italy and Germany are handled by Slovenian carriers, because they are more competitive than carriers from these countries. Some of the exports to Croatia and Hungary are also handled by Slovenian carriers (perhaps about 1 million tons), while the import flows are probably handled mainly by carriers from Hungary and Croatia.



Source: Authors, based on STAT.SI

Figure 1: The structure of services provided by Slovenian road freight

* Gross operating surplus is defined as value added at factor costs minus personnel costs (OECD, 2003).

† Turnover is defined as total value of market sales of goods and services to third parties, excluded VAT (OECD, 2003).

The corona pandemic crippled also the Slovenian economy (but only in 2020), but we can assume that the needs of the domestic market were not lower than until 2008, at least in normal circumastances. Slovenian carriers transported a similar amount of goods in 2008 and 2019, more than 91 million tons, but the difference in domestic market was almost 16.5 million tons (we don't have data on cabotage in Slovenia;- however 16.5 million are much more than 5% overall average for cabotage in EU-27). The question is who is carrying out these transports instead of Slovenian carriers and how much the Slovenian GDP is losing as a result.

We created a linear regression in which the output variable was the production value (PV) of road freight sector in Slovenia. The input variables were the amount of goods transported domestically (Qdomestic), the amount of goods loaded in Slovenia (Qloaded), the amount of goods unloaded in Slovenia (Qunloaded), and the amount of goods transported by Slovenian carriers in international transport or cabotage (Qinternational); all given in thousand tons. The following model had a very high coefficient of determination (0.983), but all variables except one, the amount of goods carried in international traffic and cabotage, were found to be statistically insignificant.

$$PV_{\text{mio€}} = 14.2501 + 0.0056 Q_{\text{domestic}} + 0.0443 Q_{\text{loaded}} + 0.1092 Q_{\text{unloaded}} + 0.0757 Q_{\text{international}}$$

So, every million tons of goods carried for the Slovenian economy in domestic transport by carriers from other countries would mean a loss of 5.6 million and a production value or about 90 million euros in 2019, which is about 3% of the total production value of the Slovenian road transport sector in that particular year. But if there was no shift to other markets (same market structure as in 2008), the loss would be much greater, around 1 billion EUR or almost a thrd of the achieved production value in 2019, as according to our model, goods unloaded in Slovenia contribute to production value of Slovenian road freight transport sector almost 20 times more than domestic traffic, and goods transported in international transport about 13.5 times more than domestic traffic.

5. CONCLUSIONS

Road freight transport is very important as it is the only mode that allows door-to-door service, so it often has no competition with other land transport modes, but competition between carriers from different European countries is very present. This is made possible by EU legislation, and carriers from the new member states, i.e. carriers from Eastern European countries, are generally more competitive due to lower personnel costs.

Slovenian carriers have recognized their competitiveness on the European market and are directing their capacities to more profitable markets. We estimate that foreign carriers in Slovenia caried about 16 million tons of cargo in 2019. If these were transported by Slovenian carriers, this would mean an additional production value of about 90 million euros (or 3% more production value). Since the capacities of Slovenian carriers are exhausted, focusing on foreign markets is a good solution, as it affects the growth of production value and directly increases the GDP; however, in doing so Slovenian carriers do not directly support Slovenian production.

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PART II

OPTIMIZATION AND MODELING IN LOGISTICS AND TRANSPORTATION

MODELLING TRANSPORT ACTIVITIES FROM INVENTORY REPLENISHMENTS IN SUPPLY CHAINS BY USE OF NUMERICAL SIMULATIONS AND MACHINE LEARNING ALGORITHMS

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Abstract: *A periodic review inventory policy represents a standard inventory management model in modern supply chains due to its many advantages. This paper studies its logistic aspects coming from the number and size of transport activities related to inventory replenishments resulting from normally distributed market demand. Due to the stochastic nature of market demand, no simple procedures or algorithms for determining the optimal values of the characteristic variables of the periodic review inventory policy exists, so extensive numerical simulations and symbolic regression analysis of a supply chain echelon are used in this paper. Equations for average order size and required number of orders related to inventory replenishments are developed with R^2 Goodness of Fit and Correlation Coefficient higher than 0.99 tested on 139.500 simulation experiments of a supply chain.*

Keywords*: supply chain management, periodic review, inventories, logistics, symbolic regression*

1. INTRODUCTION

Supply chains (SC) are dynamic systems of high complexity, operating under numerous influential factors. As one of the key elements of supply chain management, the goal of inventory control is to ensure the maximum possible fulfilment of market demand while achieving inventory levels and cost reduction in a highly competitive business environment. As freight transport mainly relies on conventional energy carriers like diesel, kerosene and heavy fuel oil, it significantly contributes to major challenges of the 21st century: pollution and climate change.

This research aims to establish relationships arising from logistical aspects of inventory replenishments in a periodic review inventory policy of a modern supply chain and offer findings to academia and practitioners. Specifically, our research analyses a minimal required number of transportation activities and their size required to fulfil normally distributed market demand for products under varying SCs working conditions. This research aims to determine the relations needed for optimisation of transport activities related to inventory replenishments in periodic review inventory policy by the use of advanced techniques of simulation modelling and machine learning. Relevant literature recognises the lack of quantitative models required to examine the possibilities of optimal solutions in terms of operative, economic, and more environmentally suitable approaches. This study aims at contributing to that direction.

1.1. Period review inventory management

Inventory management represents one of the critical processes of supply chain management to balance production and meet the market demand while keeping costs as low as possible. In this context, supply chain managers aim to reach the essential target of an efficient supply chain – having the correct quantity at the right time and in the right place (Longo F., 2011).

A well-known control policy in stochastic inventory control is the (R, s, S) policy, in which inventory is raised to an order-up-to-level S at a review instant R whenever it falls below reorder-level s. Such policies offer several practical advantages and are considered optimal by industry and academia. They facilitate optimal planning and coordination of ordering decisions in multiproduct environments.

One of the essential inventory management strategies is how the company approaches the excess demand and the occurrence of temporary stockouts – it can either be back-ordered or treated as lost sales. Although back-ordering is predominantly present in the relevant literature, according to the research of (Gruen, Corsten, & Bharadwaj, 2002), only 15 % of the customers will, in a real-life setting in an out-of-stock situation, postpone the purchase and wait for the product to be available again. The lost sales environment, which is analysed in this research paper, is prevalent in highly competitive sectors like retail, service, machinery spare parts and online sales (Gruen, Corsten, & Bharadwaj, 2002), (Breugelmans, Campo, & Gijsbrechts, 2006), (Babiloni & Guijarro, 2020). Additionally, the works of (Bashyam & Fu, 1998), (Bijvank, 2014) and (Bijvank & Vis, 2012) indicate that, since the customer satisfaction is often being a differentiation strategy among competitors, and with shortage costs particularly hard to evaluate in practice correctly, service-based requirements are more common in the real-life business sector. As recognised by (Kapalka, Katircioglu, & Puterman, 1999), adding a service-based constraint to an inventory model with lost sales makes the model more realistic but makes computation and analysis more difficult, which results in fewer publications studying this problem. There are no simple procedures or algorithms for determining the optimal values of (R, s, S) characteristic variables in real-world conditions (Babai MZ et al., 2020), (Kiesmüller GP et al., 2011). Consequently, controlling inventories by the subjective assessment, without an algorithmic basis, can result in suboptimal inventory management, increased costs, holding an inadequate amount of inventories and negative consequences such as the bullwhip effect (Žic, S. et al., 2015).

1.2. Logistics

Modern supply chains are recognised as complex systems operating in a global environment, characterised by flexibility in business operations, quick reactions to market demands and changes, the use of technological innovations such as data science, machine learning, artificial intelligence, optimisation of inventories together with the implementation of a green or sustainable approach. Transportation activities are often neglected in the research even though transportation costs can form more than 50% of the total logistics costs of a product (Swenseth S.R. and Godfrey M.R., 2002). Additionally, with uncertainty in the demand patterns, which is the usual case in real-life production and distribution situations, inventory situation gets significantly more complicated (L. Tiacci, S. Saetta, 2009). In logistics, shipment frequency is positively related to fuel consumption and carbon emissions; however, fewer but larger shipments could lead to undesirable higher inventory levels and additional costs (Tang et al., 2015). Unfortunately, many studies (Lee et al. (2005), Van Norden and Van de Velde (2005)) assume that demand data, though variable and non-stationary, must be known. When demand is no longer assumed to be deterministic, as in many production and distribution situations, the introduction of uncertainty in the demand pattern significantly complicates the inventory situation.

In logistics, transportation should provide the most room for cutting carbon emissions since it involves heavy fuel consumption (Andress et al., 2011). The amount of carbon emissions in transportation is determined mainly by transportation frequency and fuel efficiency. Shipment frequency is positively related to fuel consumption as well as carbon emissions. Subsequently, higher-order quantity and less frequent transportation would allow firms to utilise their vehicle capacity better or employ a vehicle with greater transport capacity to save total fuel consumption and reduce carbon emissions. However, fewer but larger shipments lead to undesirable higher inventory levels and additional costs. Therefore, it is natural to ponder whether this approach can reduce emissions effectively and economically and what factors impact the additional cost.

1.3. Machine learning and symbolic regression

Data modelling involves using a limited number of observations of systems variables for inferring relationships among these variables. A number of control parameters characterise the system under study. Empirical modelling attempts to express these critical control variables via other controllable variables that are easier to monitor and can be measured more accurately or timely. Control variables are referred to as outputs. Variables, or properties, used for expressing the response are called inputs or input variables. A combination of values of all input variables and the associated values of the output variables is called a scenario. The modelling task is to detect the driving input variables that cause the change in the observed response variables and formulate the relationship in the form of an accurate model. The quality of this model is assessed by the resemblance of the predicted output to the observed output based on a number of data points. For many industrial applications, the resulting relationships between the input variables and the output variables of a physical system can be found implicitly (Kleijnen, 2005; Kleijnen et al., 2005). Genetic programming (GP) for symbolic regression was first proposed by (Koza 1992) as one of several different applications of genetic programming. Since then, symbolic regression has been widely applied in many engineering sectors, such as industrial data analysis (e.g., Luo et al., 2015; Li et al., 2017), circuits analysis and design (e.g., Ceperic et al., 2014; Shokouhifar & Jalali, 2015; Zarifi et al., 2015), signal processing (e.g., Yang et al., 2005), empirical modelling (e.g., Gusel & Brezocnik, 2011; Mehr & Nourani, 2017), system identification (e.g., Guo & Li, 2012; Wong et al., 2008) and materials analysis (Mu He, Lei Zhang, 2021).

The fact that symbolic regression via GP does not impose any assumptions on the structure of the input-output models means that data determine the model structure. On the other hand, the absence of constraints on the model structure is the greatest challenge for symbolic regression since it vastly increases the search space of possibilities, which is already inherently large. Larger data sets with more input variables and more records make symbolic regression even harder. The rationale of doing the 'evolutionary' search in a vast space of alternatives is to balance the exploitation of the good solutions found so far with exploring the new areas of the search space, where even better solutions may be hiding. At least two or possibly more criteria are used for selecting' good' individuals for further propagation. Often these criteria are prediction error and model expressional complexity. Since these optimisation objectives are competing, the performance of individuals is compared concerning the Pareto-dominance relation in the objective space of model complexity and model error. In Pareto GP, model development happens parallel with automatic identification and exploitation of driving inputs that influence the observed output (Smits et al., 2005). Theoretically, GP can obtain an optimal solution if the computation time is sufficiently long.

2. EXPERIMENT DESIGN

2.1. Market demand simulation

Our model assumes stochastic demand with targeted fill rate as a service-based constraint and the lost sales environment, in which partial deliveries or backlogging is not allowed. Simulation models usually represent a suitable approach when the relations among components do not conform to simple equations or the equation is unknown (Taylor, 2003). Simulation modelling as a tool for analysing various aspects of periodic review inventory policy is present in numerous works.

This study aims to test a wide range of inventory model setup parameters to gather high accountability results. Our research model consists of an inventory simulation model operating under (R, s, S) policy whose output results represent the input information for the symbolic regression model. A general outline of this research is presented in Fig 1.

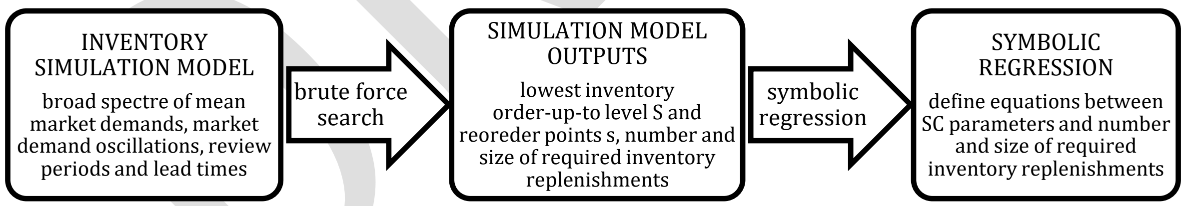

Figure 2. Research framework

The experimental design of our inventory simulation model includes normally distributed market demand with five levels of mean daily demand, three levels of demand oscillations, ten replicas of demand per each combination of mean demand and standard deviation of demand (in total, 150 simulated market demands), 30 levels of the review period, 31 level of lead time and one fill rate of 100% resulting in a total of 139.500 simulation scenarios as presented in Table 1.

Table 1. Inventory model experimental design

Mean market demand (μ)	unit/day	10, 70, 130, 190, 250
Coefficient of variation of market demand (CV)		0.1, 0.2, 0.3
Inventory service performance measures		fill rate (β-service level)
Service levels	%	100
Delivery lead time (LT)	day	0, 1, 2, ... 30
Review period (R)	day	1, 2, 3, ... 30

The minimal value of CV=0.1 for each value of μ represents the market demand with minimal oscillations. As the oscillations of market demand increase, minimal values of daily market demand get closer to 0, increasing the range between minimal and maximal values of μ to twice the average values. Such high oscillations will result in a significant increase of s and S inventory levels to fulfil the same fill rate compared to the same μ with lower oscillations. Market demand and order size are of non-negative integer values. Market demand is observed for 365 days and can be of value 0 due to the stochastically modelled normally distributed demand. For uniformity of simulation experiments, simulation experiments (SE) start on Monday with inventory levels set to order up to level S. Deliveries executed within the same working day on which the order was launched are referred to as replenishments with zero lead time. Generation of market demands is done in Python and analysis in Prism for Windows, version 9.0.0. Results are visible in table 2, in which each column represents average values of 10 market demands.

Table 2. Descriptive statistics of 150 simulated market demands

Mean	**10**			**70**			**130**			**190**			**250**		
Std. Deviation	**1**	**2**	**3**	**7**	**14**	**21**	**13**	**26**	**39**	**19**	**38**	**57**	**25**	**50**	**75**
Std. Error of Mean	0,1	0,1	0,2	0,4	0,7	1,0	0,7	1,0	2,0	1,0	2,0	3,0	1,0	3,0	4,0
Minimum	7,2	4,4	1,6	49,6	30,3	10,9	92,2	55,7	24,8	130,8	83	27	175,9	107,4	27,7
25% Percentile	9	9	8	65,2	60,2	55,6	121,3	113	103,2	176,9	165,4	152,4	233,3	216,7	198,1
Median	10	10	10	70	70,1	69,5	130	129,9	130	190,3	189,5	189,6	250,1	249,8	250,3
75% Percentile	11	11	12	74,8	79,3	84,2	139	148	156,9	202,8	216	228,1	267,2	283,3	300,6
Maximum	13	15,6	19,2	90,6	109,5	129,5	168,5	207,4	246,8	246,6	308,3	359,9	321,8	399,8	476,5
Range	5,8	11,2	17,6	41	79,2	118,6	76,3	151,7	222	115,8	225,3	332,9	145,9	292,4	448,8
Lower 95% CI of mean	10	10	10	69	69	68	129	127	126	188	186	184	247	245	242
Upper 95% CI of mean	10	10	10	71	71	72	131	133	134	192	194	196	253	255	258
Coefficient of variation	0,1	0,2	0,3	0,1	0,2	0,3	0,1	0,2	0,3	0,1	0,2	0,3	0,1	0,2	0,3
Geometric mean	10	10	9,1	70	69	66	129	127	123,1	189	186	179,9	249	245	236,9
Harmonic mean	10	10	9	69	67	61,4	129	124,1	114	188	181,7	166,2	247	239	217,5
Skewness	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
Kurtosis	-0,1	-0,1	0,0	0,0	-0,2	-0,2	0,0	0,0	0,0	0,1	0,1	0,0	-0,1	0,0	0,0

Table 3 shows that all 150 simulated marked demands have passed the normality test according to D'Agostino-Pearson omnibus test from the same Prism software.

Table 3. D'Agostino-Pearson omnibus test of 150 simulated market demands

Mean	10			70			130			190			250		
Std. Deviation	**1**	**2**	**3**	**7**	**14**	**21**	**13**	**26**	**39**	**19**	**38**	**57**	**25**	**50**	**75**
K2	3,62	1,70	0,33	0,47	2,47	1,27	0,18	2,13	1,88	5,04	0,91	0,18	1,97	0,24	2,09
P value	0,16	0,43	0,85	0,79	0,29	0,53	0,91	0,34	0,39	0,08	0,64	0,91	0,37	0,89	0,35
Passed normality test (α=0.05)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

2.2. Brute force search for lowest characteristic inventory levels s and S

The model uses brute force search to determine the lowest values of s and S, which fulfil the targeted fill rate and satisfy the operating conditions in a total observed period of 365 days. Inventory model outputs represent the basis for the extensive search by symbolic regression method, which results in modelling equations for average order size and required number of inventory replenishments in an observed period.

Fill rate (β) is a quantity-oriented measure, representing the quantity of demand in the observed period which is satisfied from inventory on the stock without back-ordering. This form of service performance measure is relevant for practitioners since it provides a fraction of demand which is turned into sales (Tempelmeier, 2007), (Chopra & Meindl, 2013), (Luo, Bai, Zhang, & Gill, 2014), (Silver, Pyke, & Thomas, 2016). This paper will use fill rate as a service performance measure, calculated according to Eq. 1.

$$\boldsymbol{\beta} = \frac{\boldsymbol{number\ of\ units\ supplied\ from\ the\ stock}}{\boldsymbol{total\ demand}} \tag{1}$$

For this paper, the authors extensively analysed a unique group of β=100%, which is realistic and welcomed in business practice, but theoretical research of such operating conditions of inventory systems is not significantly present. This is so because it was impossible to calculate z value (related to the service level) of normally distributed market demand for which 100% corresponds to an infinitely high value. A schematic view of the data matrix of a simulated supply chain is visible in figure 2.

		Input variables						Responses			
		x_1	x_2	x_3	x_4	x_5	x_6	y_1	y_2	y_3	y_4
	No	μ	SD	replica	R	LT	β	s	S	average order size	replenishments count
Data records	1	•	•	•	•	•	•	•	•	•	•
	2	•	•	•	•	•	•	•	•	•	•
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	139.500	•	•	•	•	•	•	•	•	•	•

Figure 3. Schematic view of data matrix of the simulated supply chain where each line corresponds to a specific scenario; adopted according to (Vladislavleva, 2008)

In order to determine specific s and S values of simulation experiments with the brute force search, it is needed to test Z simulation experiments according to equation 2. Two HP DL580 G8 servers were used for this highly numerically intensive problem. Each server was equipped with 4 Intel Xeon processors with 30 logical cores and 256 GB RAM. In total, $3{,}33 \cdot 10^{12}$ simulation experiments of (R, s, S) inventory control policy were tested to determine 139.500 simulation experiments with the lowest characteristic values for operating conditions. The total computational time for the two above mentioned servers with 120 logical cores each was 4 days, 16 hours and 9 minutes.

$$\boldsymbol{Z = 1 + s - \frac{S - S^2}{2}} \qquad (2)$$

Lowest number of required tested simulation experiments, 84 of them were required for μ =10, SD=1, LT=0 and (R, s, S) = (1, 5, 13), which occurred twice. On the other side, the highest number of tested scenarios, 272.732.526 of them, was needed for μ =250, SD=50, LT=30 and (R, s, S) = (30, 16190, 23355), resulting in 3.28 million times more simulation experiments needed for solving one inventory setup with long delivery time, rare review period and high mean values. Results of 139.500 simulation experiments were tested, and characteristic values of (R, s, S) inventory policy were extracted for further analysis. Double-precision values were used since precision, and an adequate number of simulation experiments are of utmost importance for modelling equations by machine learning and symbolic regression processes.

2.3. Modelling responses of (R, s, S) inventory policy with symbolic regression

We used Eureqa demo version 1.24 (Nutonian, 2015) for the modelling part, a software package based on symbolic regression to determine the relationship between the independent and dependent variables. The software searches the fitting parameters and the form of the equations simultaneously (Schmidt and Lipson, 2009). Eureqa's genetic algorithm is multi-objective; two objectives are complexity and error, regardless of the error metric chosen. Eureqa searches for a formula by combining mathematical building blocks, which were: add, subtract, multiply, divide, modulo, square root, min and max. Authors intentionally left out usually used building blocks constants and integer values because they tend to overfit developed models to specific values of input variables and reduce practitioners and academia adaptability of proposed models.

Training and validation data were split equally among 139.500 records and shuffled. As in many industrial and engineering applications recommended, the error metric used was mean squared error (MSE). MSE is the metric that assesses the quality of the forecasting model or predictor. MSE also incorporates both the variance and bias (the distance of predicted value from its actual value). This metric penalises large errors or outliers more than minor errors. Model generation and searches for Pareto optimal equations lasted for 12h on the HP DL580 G8 server for each of the two models. In that time, approximately $3 \cdot 10^{13}$ formulas and $1{,}9 \cdot 10^{6}$ generations were tested.

3. MODELS

The best model selection compromises the minimum acceptable coefficient of determination R^2 and maximum complexity. Equation 3 presents a newly modelled equation for average order size (AOS) for echelon working under normally distributed market demand under (R, s, S) inventory policy and equation 4 required number of inventory replenishments in an observed period N depending on a review period and lead time (RC). It is understood that observed period N must be several times longer than the maximal value of R+LT in order for characteristic inventory values to stabilise. Also, R, LT and N should be in the same time units.

$$\boldsymbol{AOS = \mu\left(R + LT - mod\frac{LT}{R}\right)} \qquad (3)$$

$$\boldsymbol{RC} = \frac{\boldsymbol{N}}{\boldsymbol{R} + \boldsymbol{LT} - \boldsymbol{mod}\frac{\boldsymbol{LT}}{\boldsymbol{R}}} \tag{4}$$

As it can be seen from Table 4, statistics of proposed models show high values of R^2 Goodness of Fit and Correlation Coefficient. The equation for average order size shows minimal values for R^2 of 0.997231 and the equation for correlation coefficient of 0.999034. Mentioned values show that proposed equations, albeit simple and tested on an extensive data set of 139.500 simulation experiments, not using integer or decimal constants and not considering SD, are precise even for experimental setups and models.

Table 4. Models statistics

	Average order size	Order count
Mean Absolute Error	52.838	0.420916
Mean Square Error	17663.5	0.626786
R^2 Goodness of Fit	0.997231	0.998439
Correlation Coefficient	0.999034	0.999449
Rank Correlation	0.999	0.996
Maximum Error	1369.83	58
Inter-quartile Absolute Error	7.080	0.338
Signed Difference Error	-43.091	-0.349
Hybrid Correlation Error	0.024	0.022
AIC Error	1.364e+06	-65147.5

Based on the proposed equation, Figure 3 shows an increase in average order size for all tested scenarios based on the mean market demand of 1 product/day. These values can be used for linear scaling to specific mean marked demand in supply chains with periodic review policy. From figure 3 it is visible that if the lead time is multiple of the review period, an increase in average order size will be most significant.

Based on the proposed equation, Figure 4 shows a reduction in the required number of inventory replenishments in an observed period for all tested scenarios. These values are not sensitive to mean market demand or standard deviation of it. From figure 4 it is visible that if the lead time is multiple of the review period, a reduction in the required number of inventory replenishments will be most significant.

3. CONCLUSION

In this paper, authors have analysed (R, s, S) periodic review inventory policy for working conditions of lead time and review period up to 30 days, normally distributed mean market demand between 10 and 250 products daily, CV between 0.1 and 0.3. In total, 139.500 simulation experiments were used for machine learning algorithms to model new equations for average order size and required number of inventory replenishments in an observed period. Proposed equations with values of R^2 Goodness of Fit and Correlation Coefficient higher than 0,99 allow scientists and practitioners to model logistic aspects of the supply chain working under (R, s, S) inventory policy for fulfilling 100% of market demand, reduce SC costs and GHG emissions and optimally plan inventory replenishment activities without reducing the percentage of market demand fulfilment. Proposed equations are simple and do not require the calculation of standard deviation, making them even more useful for supply chain practitioners.

R	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	60
29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	58	58
28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	56	56	56
27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	54	54	54	54
26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	52	52	52	52	52
25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	50	50	50	50	50	50
24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	48	48	48	48	48	48	48
23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	46	46	46	46	46	46	46	46
22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	44	44	44	44	44	44	44	44	44
21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	42	42	42	42	42	42	42	42	42	42
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40
19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	38	38	38	38	38	38	38	38	38	38	38	38
18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	36	36	36	36	36	36	36	36	36	36	36	36	36
17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	34	34	34	34	34	34	34	34	34	34	34	34	34	34
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	45
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	28	28	28	28	28	28	28	28	28	28	28	28	28	28	42	42	42
13	13	13	13	13	13	13	13	13	13	13	13	13	13	26	26	26	26	26	26	26	26	26	26	26	26	26	26	39	39	39	39	39
12	12	12	12	12	12	12	12	12	12	12	12	12	24	24	24	24	24	24	24	24	24	24	24	24	36	36	36	36	36	36	36
11	11	11	11	11	11	11	11	11	11	11	11	22	22	22	22	22	22	22	22	22	22	22	33	33	33	33	33	33	33	33	33
10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	20	20	20	20	20	20	30	30	30	30	30	30	30	30	30	30	40
9	9	9	9	9	9	9	9	9	9	18	18	18	18	18	18	18	18	18	27	27	27	27	27	27	27	27	27	36	36	36	36
8	8	8	8	8	8	8	8	8	16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	32	32	32	32	32	32	32
7	7	7	7	7	7	7	7	14	14	14	14	14	14	14	21	21	21	21	21	21	21	28	28	28	28	28	28	28	35	35	35
6	6	6	6	6	6	6	12	12	12	12	12	12	18	18	18	18	18	18	24	24	24	24	24	24	30	30	30	30	30	30	36
5	5	5	5	5	5	10	10	10	10	10	15	15	15	15	15	20	20	20	20	20	25	25	25	25	25	30	30	30	30	30	35
4	4	4	4	4	8	8	8	8	12	12	12	12	16	16	16	16	20	20	20	20	24	24	24	24	28	28	28	28	32	32	32
3	3	3	3	6	6	6	9	9	9	12	12	12	15	15	15	18	18	18	21	21	21	24	24	24	27	27	27	30	30	30	33
2	2	2	4	4	6	6	8	8	10	10	12	12	14	14	16	16	18	18	20	20	22	22	24	24	26	26	28	28	30	30	32
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

LT

Figure 4. Average order size for review period and lead time up to 30 days for mean market demand of 1 product/day under (R, s, S) inventory policy according to Eq. 3

R	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	6
29	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	6	6
28	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	7	7	7
27	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	7	7	7	7
26	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	7	7	7	7	7
25	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	7	7	7	7	7	7
24	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	8	8	8	8	8	8	8
23	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	8	8	8	8	8	8	8	8
22	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	8	8	8	8	8	8	8	8	8
21	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	9	9	9	9	9	9	9	9	9	9
20	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	9	9	9	9	9	9	9	9	9	9	9
19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	10	10	10	10	10	10	10	10	10	10	10	10
18	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10	10	10	10	10
17	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	11	11	11	11	11	11	11	11	11	11	11	11	11	11
16	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
15	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8
14	26	26	26	26	26	26	26	26	26	26	26	26	26	26	13	13	13	13	13	13	13	13	13	13	13	13	13	13	9	9	9
13	28	28	28	28	28	28	28	28	28	28	28	28	28	14	14	14	14	14	14	14	14	14	14	14	14	14	9	9	9	9	9
12	30	30	30	30	30	30	30	30	30	30	30	30	15	15	15	15	15	15	15	15	15	15	15	15	10	10	10	10	10	10	10
11	33	33	33	33	33	33	33	33	33	33	33	17	17	17	17	17	17	17	17	17	17	17	11	11	11	11	11	11	11	11	11
10	37	37	37	37	37	37	37	37	37	37	18	18	18	18	18	18	18	18	18	18	12	12	12	12	12	12	12	12	12	12	9
9	41	41	41	41	41	41	41	41	41	20	20	20	20	20	20	20	20	20	14	14	14	14	14	14	14	14	14	10	10	10	10
8	46	46	46	46	46	46	46	46	23	23	23	23	23	23	23	23	15	15	15	15	15	15	15	15	11	11	11	11	11	11	11
7	52	52	52	52	52	52	52	26	26	26	26	26	26	26	17	17	17	17	17	17	17	13	13	13	13	13	13	13	10	10	10
6	61	61	61	61	61	61	30	30	30	30	30	30	20	20	20	20	20	20	15	15	15	15	15	15	12	12	12	12	12	12	10
5	73	73	73	73	73	37	37	37	37	37	24	24	24	24	24	18	18	18	18	18	15	15	15	15	15	12	12	12	12	12	10
4	91	91	91	91	46	46	46	46	30	30	30	30	23	23	23	23	18	18	18	18	15	15	15	15	13	13	13	13	11	11	11
3	122	122	122	61	61	61	41	41	41	30	30	30	24	24	24	20	20	20	17	17	17	15	15	15	14	14	14	12	12	12	11
2	183	183	91	91	61	61	46	46	37	37	30	30	26	26	23	23	20	20	18	18	17	17	15	15	14	14	13	13	12	12	11
1	365	183	122	91	73	61	52	46	41	37	33	30	28	26	24	23	21	20	19	18	17	17	16	15	15	14	14	13	13	12	12

LT

Figure 5. Rounded values of the required number of inventory replenishments in an observed period of 365 days for review and lead time up to 30 days under (R, s, S) inventory policy according to Eq. 4

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ROUTING OF VEHICLES FOR AID DELIVERY IN DISASTER RESPONSE

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Abstract: *Due to limited resources and response times, logistics has played a crucial role in managing events that require humanitarian assistance. One of the major actions in the response stage of relief logistics is distribution of supplies in order meet the basic subsistence needs of affected people. In this paper, a routing problem for humanitarian aid distribution in the event of a humanitarian disaster is solved. In the response stage, first-aid resources have to be provided for affected people in large geographical areas. Different service points are selected where users can be served. Each beneficiary has access to at least one service point. A mixed integer linear programming model of team orienteering problem with overlaps is presented to determine efficient vehicle routes, subjected to maximum duration constraints, miximizing the number of served beneficiaries. To solve the problem, a population-based simulated annealing algorithm (PBSA) is developed. This PBSA algorithm is compared with simulated annealing (SA) algorithm. The population-based solution approach outperforms the SA on all of the instances.*

Keywords*: disaster response, vehicle routing, simulated annealing, first-aid resources.*

1. INTRODUCTION

The term disaster represents an event with the most severe consequences for people, nature, facilities, economy and society. Natural disasters, such as earthquakes, floods, fires etc., are an integral part of human history. Only in the first two decades of the 21st century, humanity was hit by an earthquake and tsunami in the Indian Ocean (2004), an earthquake in Haiti (2010) or a typhoon in the Philippines (2013).

The numbers of deaths and injuries involved, displaced people or otherwise affected by these natural disasters are mind-numbing. In managing these events logistics has played a crucial role. Limited resources and response times, high degrees of uncertainty and a lack of reliable data, make logistics decisive in carrying out the relief operations. Thus, logistical efforts account for 80% of disaster relief operations (Trunick 2005).

The disaster stage of relief logistics consists of four phases: mitigation, preparedness, response, and recovery (McLoughlin 1985). Response includes the actions taken directly

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before, during, and immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of affected people. Limited resources result in difficulties in responding to the needs of the affected population quickly and effectively.

In this paper, a routing problem for humanitarian aid distribution in the event of a humanitarian disaster is solved. In the response stage, first-aid resources (food, drugs, other supplies) and services have to be provided for affected people in large geographical areas. Different service points are selected where users can be served. Each beneficiary has access to at least one service point. A set of vehicles provides the service points with first-aid resources within a given time period. On days immediately after a disaster, resources such as vehicles are in short supply. The problem is to decide which service point to supply to maximize the number of beneficiaries that have access to service points. This problem is modeled with a mixed integer linear programming model of team orienteering problem with overlaps.

The team orienteering problem (TOP) is a decision-making problem of the class of the vehicle routing problem with profits (Archetti et al. 2014). Given a set of vehicles and a set of customers, each one with an associated profit, the goal of the TOP is to design a set of routes (one for each vehicle) that maximizes the total profit collected by visiting (some of) the customers without exceeding a maximum duration constraint for each route.

There is an analogy between customers and profits in the team orienteering problem and service points and beneficiaries in the problem considered in this paper. In both cases it is necessary to collect as much profit or supply with humanitarian aid as many people as possible after natural disaster. In real-life, some beneficiaries may use more than one service point, which causes overlaps of the points. It introduces a new type of orienteering problem known as orienteering problem with overlaps (TOPO). The TOPO is inspired by a problem in charge of providing cash collection, counting, and distribution in the group of three banks in Netherlands (Orlis et al. 2020). One of the main challenges is to decide which automated teller machines to replenish by using a set of vehicles, subjected to working hours, to maximize the number of bank account holders that have access to these cash machines. It is assumed that bank account holders (identified by the postal code of residence) have access to cash if there exists a replenished automated teller machine within five kilometers from the residence postal code. Usualy, there are users who have access to multiple cash machines, which causes overlaps. The next application of the TOPO is the real-life distribution problem with the decision on which stores to replenish given that beneficiaries can be served from one or several nearby stores.

Figure 1 shows an example of an instance with 4 service points and 10 beneficiaries and a feasible solution for the instance. Two vehicles are used. The first serves service points 1 and 2, whereas the other serves just point 4. This solution serves nine beneficiaries. Notice that beneficiaries 3 and 4 can access both service points, but they do not count twice in the total number of beneficiaries served.

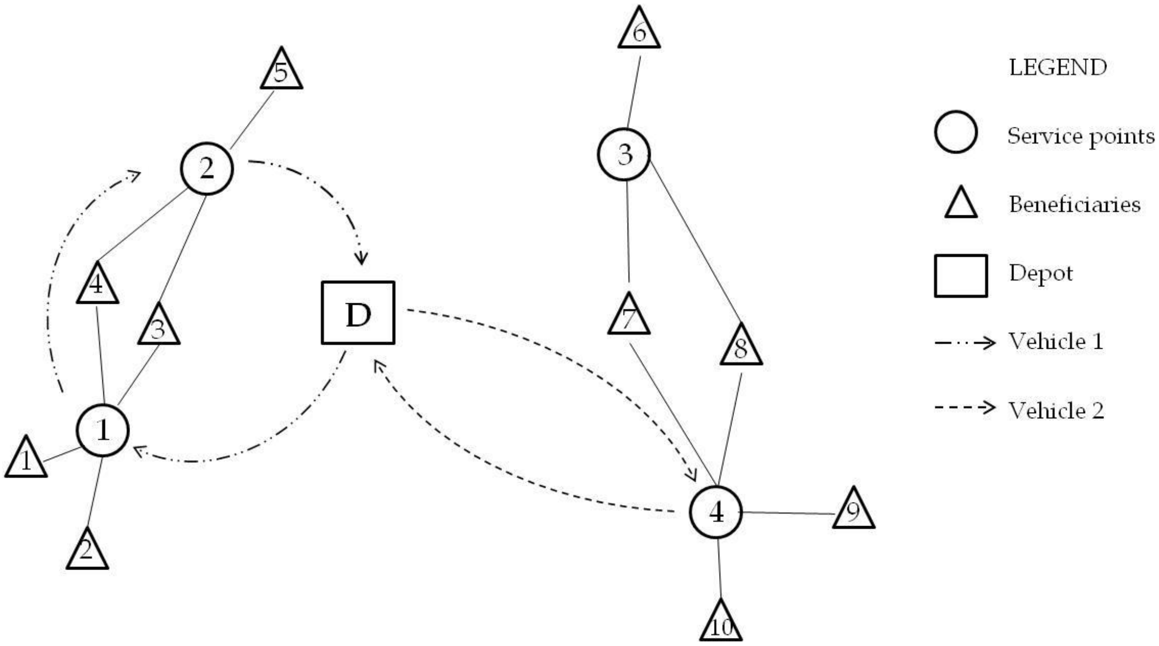

Figure 1. Example of a TOPO instance and a corresponding feasible solution

The main contributions of this paper are the following. A real-life problem of routing vehicles for first-aid delivery in disaster relief is modeled as a TOPO and a population-based simulated annealing (PBSA) algorithm that is able to find high-quality solutions of instances with 200 service points and more than 50000 beneficiaries, as well as those with 400 service points and almost 300000 beneficiaries within short computation times is proposed for the problem.

The rest of this paper is organized as follows. In Section 2 the main contributions from the literature on delivery of first-aid resources are reviewed, while the TOPO is introduced in Section 3. The PBSA algorithm is described in Section 4. The computational results obtained by applying the PBSA and SA algorithms on a set of instances are discussed in Section 5. Finally, conclusions and future research directions are outlined in Section 6.

2. LITERATURE REVIEW

Many studies were conducted using operations research techniques to facilitate the delivery of humanitarian aid. Some of them deal with inventory systems for disaster relief, facility location to site warehouses or routing of vehicles after disaster.

Based on data collected from warehouse operations in Kenya, Beamon and Kotleba (2006) developed a stochastic inventory control model that determines optimal order quantities and reorder points for a long-term emergency relief response. Oh and Haghani (1996) formulate a multicommodity, multi-modal network flow model for a generic disaster relief operation and solve with two heuristics. Ozdamar et al. (2004) developed a dynamic time-dependent transportation problem that needs to be solved repetitively at given time intervals during ongoing aid delivery. New plans are obtained based on new requests for aid materials, new supplies and transportation means and they contain the optimal mixed pick up and delivery vehicle schedules within the considered planning period, as well as the optimal quantities and types of loads picked up and delivered on these routes.

Oruc and Kara (2018) propose a post-disaster assessment strategy as part of response operations in which effective and fast relief routing are of utmost importance. In particular, the road segments and the population points to perform assessment activities on are selected based on the value they add to the consecutive response operations. A bi-objective mathematical model that provides damage information in the affected region by considering both the importance of population centers and road segments on the transportation network is developed. The first objective aims to maximize the total value added by the assessment of the road segments whereas the second maximizes the total profit generated by assessing points of interests.

Pérez-Rodríguez and Holguín-Veras (2015) developed mathematical models that maximize the benefits derived from the distribution of critical supplies to populations in need after a disaster. An inventory-allocation-routing model for the optimal assignment of critical supplies that minimizes social costs is developed in the paper. Also, heuristic methods are provided along with numerical experiments to assess their performance. The formulations are based on welfare economics and the use of social costs, which are incurred by the segments of society involved in, and impacted by, the relief distribution strategy.

Eisenhandler and Tzur (2018) dealed with logistic aspect of a food bank that on a daily basis uses vehicles of limited capacity to distribute food collected from suppliers, under an imposed maximal traveling time. The problem is model as a routing resource allocation problem, with the aim of maintaining equitable allocations to the different agencies while delivering overall as much food as possible. An exact solution method, a heuristic approach and numerical experiments on several real-life and randomly generated data sets, are presented.

The routing of vehicles carrying critical supplies can greatly impact the arrival times to those in need. There are articles which discuss both the classic cost-minimizing routing problems and problems with alternative objective functions. Because deliveries should be fast but fair too, Campbell et al. (2008) solve the traveling salesman problem (TSP) and the vehicle routing problem (VRP) with two alternative objective functions: one that minimizes the maximum arrival time and one that minimizes the average arrival time. As a research on alternate objectives for vehicle routing the following papers can be mentioned. França et al. (1995) solved m-TSP where the length of the longest tour is minimized. Averbakh and Berman (1996) consider the two-TSP, where two salesmen must together visit all of the nodes on a tree. The objective is to minimize the length of the longest of the two tours while Applegate et al. (2002) dealed with VRP where the length of the longest of four routes is minimized.

3. MATHEMATICAL MODEL

The TOPO can be formally described as follows (Orlis et al. 2020). A set of beneficiaries B is given. Beneficiaries are served via a set of service points $S=\{1,2,\ldots,n\}$; in particular, each beneficiary $b \in B$ can be served by a subset of service points $S_c \in S$. Similarly, the subset of beneficiaries that can be served by service point $i \in S$ is indicated by $Bi \subseteq B$. Beneficiariers can be served via the service points by routing a set of homogeneous vehicles K located at a depot, indicated by 0. Each vehicle can perform a route that starts from the depot, visits some service points, and returns to the depot. Each route cannot exceed a maximum route duration denoted by T_{max}. The travel time between each pair of depot/service point locations i and j ($i, j \in V = S \cup \{0\}$) is indicated by t_{ij}. Travel times can be asymmetric and, without loss of generality, are assumed to be strictly positive and to satisfy the triangle inequality (i.e., $t_{ij} \leq t_{ik} + t_{kj}$ for each $i, j, k \in V$). The TOPO aims at finding a set of routes, each one not exceeding the maximum route duration, that visit each service point at most once and maximize the number of beneficiariers served.

The TOPO can be defined on a directed graph $G(V,A)$, where the arc set is defined as $A=\{(i,j)|i,j \in V, i \neq j\}$. Let us define the following three sets of variables: $x_{ij} \in \{0,1\}$, a binary variable equal to 1 if arc $(i,j) \in A$ is traversed by one of the vehicles (0 otherwise); $y_b \in \{0,1\}$, a binary variable equal to 1 if beneficiary $b \in B$ is served (0 otherwise); and $z_i \in R^+$, a continuous variable indicating the arrival time at service point $i \in S$. Then, the TOPO can be formulated as follows:

$$z^* = \max_{b \in B} y_b \tag{1}$$

$$s.t. \quad \sum_{(0,j) \in A} x_{0j} \leq |K| \tag{2}$$

$$\sum_{(i,j) \in A} x_{ij} \leq 1, \quad i \in S \tag{3}$$

$$\sum_{(i,j) \in A} x_{ij} = \sum_{(j,i) \in A} x_{ji}, \quad i \in S \tag{4}$$

$$z_i + \left(Tmax + t_{ij}\right) x_{ij} \leq z_j + Tmax, \quad (i,j) \in A: i,j \in S \tag{5}$$

$$t_{0i} \sum_{(i,j) \in A} x_{ij} \leq z_i \leq (Tmax - t_{i0}) \sum_{(i,j) \in A} x_{ij}, \quad i \in S \tag{6}$$

$$\sum_{(i,j) \in A: i \in S_b} x_{ij} \geq y_b, \quad b \in B \tag{7}$$

$$x_{ij} \in \{0,1\} \quad (i,j) \in A \quad y_b \in \{0,1\} \quad b \in B \quad z_i \in R^+, \quad i \in S \tag{8}$$

The objective function (1) asks for maximizing the number of beneficiaries served. Constraint (2) ensures that no more than $|K|$ routes are designed. Constraints (3) guarantee that each service point is visited at most once. Constraints (4) are flow conservation constraints for the service points. Constraints (5) link x and z variables to set the arrival time at each service point based on the traversed arcs and also prevent subtours in the designed routes. Constraints (6) guarantee that if service point $i \in S$ is visited, the arrival time of the vehicle visiting it is not less than the travel time from the depot to i and not greater than T_{max} - t_{i0}. Constraints (7) ensure that each beneficiary $b \in B$ is served only if at least one of the service points of the set S_b is visited. Constraints (8) define the range of the decision variables.

4. SOLUTION METHODS

Simulated annealing (SA) is a discrete optimization technique of combining the principle of deterministic descends strategy with Monte Carlo approach. Kirkpatrick et al. (1983) and Cherny (1985) independently pointed out the analogy between the activities of the thermodynamic system and the search for the global minimum in the problems of discrete optimization. In searching for the optimal solution, the SA utilizes a stochastic approach. Local optima are avoided through accepting non-improving solutions with a certain probability in each temperature. Different applications of the SA can be found in the literature for solving many non-polynomial hard optimization and operation research problems.

In this paper, a population-based simulated annealing (PBSA) is applied which has a similar structure to SA though had been developed by varying in number of initial solutions in order to achieve more accurate solutions by diversification. Some of the applications of the PBSA can be found in papers of Jolai et al. (2012), Shaabani and Kamalabadi (2016).

A solution is encoded as a permutation of integers which represent service points to be visited. Based on an example of an area with 10 service points (Figure 2) each vehicle in the solution is assigned a sequence of service points to be visited during the planning period (minimum route duration).

7	2	3	10	1	5	6	9	4	8
Vehicle 1			Vehicle 2			Vehicle 3		unassigned	

Figure 2. An example of solution representation

In the example solution (Figure 2), there are three vehicles. Vehicle 1 and 2 are assigned three service points each, while the thirth vehicle visits two service points. In this solution, service points 4 and 8 are not assigned.

The fitness function of the solution corresponds to the negative equivalent of objective function (2) which represents the total number of beneficiaries "collected" from all service points in the order of the visits given by the solution.

The SA (also the PBSA) is basically a simulation of the recrystallisation of atoms in metal during its annealing. It begins with a starting temperature denoted by τ_0 which decreases until it reaches its final number of iterations (It) using an annealing schedule to define how the temperature has changed during the annealing process. In this paper the geometric cooling approach is adopted and the temperature is decreased according to the scheme $\tau_{i+1} = \alpha\tau_i$, where α represents a positive constant number less than one named cooling factor, after L moves of stage length.

Algorithm proceeds by creating feasible initial solution x_0 wich is repeated n_{pop} times to form a primary population (of size n_{pop}).

The feasible initial solution x_0 is obtained in a few steps. First, the service points are sorted in decreasing order of number of beneficiaries associated with them. The service points are assigned to the vehicle until constraint related to the maximum route duration of the vehicle is not violated. On that way, algorithm obtains subsets of service points assigned to the vehicles, as well as subset of service points which will not be visited.

According to the fitness of the problem, the cost of each candidate is calculated in order to determine the best solution at each temperature. These best solutions are used to generate the next candidates using an approach such as neighbourhood generation.

For the neighbourhood procedure three cases are applied: swap, reversion and insertion. The *swap* rule implies the replacement of two randomly selected service points from the current solution. *Reversion* rule means alter of the order of all service points between two arbitrarily selected service points, including them as well, so that the first becomes the last one, etc. *Insert* rule interpolates the arbitrary service point in a randomly selected position, omitting the service point on its previous position. The neighborhood relation is defined as the movement of a service point to a new position in the sequence. The movement of an assigned service point to the subset of anassigned service points is forbidden.

The algorithm accepts candidates if there is improvement in the fitness but, to avoid local optimum solutions, the algorithm also allows others to be kept with a probability obtained from Boltzman distribution which equals $e^{\frac{-\Delta f}{k\tau}}$ where Δf is the difference in fitness between the old and new states and τ denotes the temperature of the process and k is a constant parameter of the process.

The current temperature τ is decreased after running L iterations (maximum iteration per temperature) according to a cooling schedule.

In the PBSA, if each member of the current population (of size n_{pop}) generates n_{move} neighbors at each iteration, $n_{pop} \cdot n_{move}$ new solutions will be created. All the generated neighbors are placed in a set. Members of this set will be compared with each other, and n_{pop} number of best members will be selected. This procedure guarantees that each member of the population will interact with all generated neighbors, rather than just its own neighbors. In accordance with the previous procedure, again n_{move} neighbors should be generated for each of n_{pop} best selected members, and the entire process repeated until the termination condition is fulfilled.

6. NUMERICAL EXPERIMENTS

The computational results obtained by applying the proposed PBSA and SA algorithms on the set of problem instancies are presented in this section.

The possibilities of the developed metaheuristics are presented on a set of 18 numerical examples which are created in the following way. First, two networks were simulated, with 200 and 400 nodes representing service points, respectively. For the first network (n=200 nodes and the depot), coordinates (x, y) of service points are simulated according to the uniform distribution U[0, 45], while the number of beneficiaries (profit in service point) is simulated by the uniform distribution U[100, 900]. The set of the maximum route duration values is {90, 100, 110}, while the set of the numbers of vehicles is {14, 15, 16}, which makes 9 examples in total. For the other network (n=400 nodes and the depot) coordinates (x, y) are simulated according to the uniform distribution U[0, 150], while the number of beneficiaries is simulated according to the uniform distribution U[100, 4000]. The set of the maximum route duration values is {250, 260, 270}, while the set of the numbers of vehicles is {55, 56, 57}, which makes 9 examples, 18 in total. It is assumed that the coordinates of the nodes and the route duration are of the same dimensions. The total number of beneficiaries are 50825 and 291838 for the first and the second network, respectively.

Than, similar to the procedure presented in Orlis et al. (2020), a service radius ρ defining the maximum distance between a service point and the beneficiaries it can serve is computed as $\rho = 0.5 \cdot min\{t_{ij} \mid i,j \in S, i \neq j\}$. The service radius ρ subsequently is used to define nonoverlapping circular service regions centered around each service point. Then, for every service point, within its service region, as many beneficiaries as the profit of the associated service point are allocated. In the end, the smallest value of ρ such that $\Sigma_{i \in S}|C_i| \geq (1+\gamma) \cdot |C|$ is computed, where γ is degree of overlap.

The value of the parameters τ_0, L and α are determined according to the suggestion proposed in Johnson et al. (1989). The parameter L is given to be 3 times the number of the vehicles, τ_0=25, α=0.95, probability distribution p=[0.3, 0.4 0.3], the number of iterations It=2000. Specially, for the PBSA, the population size is 5, while the number of moves is 3. Degree of overlap γ equals 10%.

The developed PBSA and SA algorithms were implemented in MATLAB 7.6.0. on a 3.20 GHz Intel Core i5-3470 64-bit computer with 8 GB of RAM.

Table 1 summarizes the computational results of the PBSA and the SA algorithms applied on 18 created instances. Columns report the following information: the ordinal number of instances along with the number of the service points n and the number of beneficiaries |B|, the maximum route duration (T_{max}), the number of vehicles (|K|), the number of served beneficiaries obtain by the PBSA and the SA algorithm (B_{PBSA} and B_{SA}, respectively), running time of the algorithms (t_{PBSA} and t_{SA}), relative difference between the number of served beneficiaries obtain by the PBSA and the SA algorithm (B_{PBSA} - B_{SA})/ B_{PBSA}).

Table 1 indicates that the SA algorithm based on population (PBSA) has a better performance than the classical SA algorithm. Columns 4 and 6 show that the values of the number of served beneficiaries obtained by the PBSA is greater than those obtained by the SA for all instances. The superiority is shown in column 8, too, where the relative differences between the total served beneficiaries obtained by the PBSA and the SA are given. For the first set of 9 instances (n=200) the average value of relative differences between the total served beneficiaries is 1.47%, while for the second set of 9 instances (n=400) it is 2.25%.

In addition to the values of relative differences, run times of the algorithms are presented in Table 1. It can be seen that the average run times of both algorithms are very reasonable. For the set of 9 instances and 200 service points run times are in average 515.17 sec. and 282.85 sec. for the PBSA and the SA, respectively, while for the set of 9 instances and 400 service points the average execution times equals 1512.56 sec and 864.48 sec., respectively. It takes longer to solve the instances by the PBSA, but not significantly. Both algorithms are appropriate for application in real time.

It can be observed that for all maximum route duration, the greater the number of vehicles the greater the number of beneficiaries served on all instances. Generally, the proposed PBSA algorithm has respectable potentials for a practical application.

Table 1. Comparison of the results obtained by the PBSA and the SA

n=200 |B|=50825	T_{max}	|K|	B_{PBSA}	t_{PBSA}	B_{SA}	t_{SA}	(B_{PBSA} - B_{SA})/ B_{PBSA} (%)
1	90	14	43888	462.95	43261	213.47	1.43
2		15	45732	484.45	45138	219.89	1.3
3		16	47011	494.24	46474	268.90	1.14
4	100	14	47161	500.46	46242	263.02	1.81
5		15	47352	524.80	46497	301.29	1.94
6		16	48241	554.59	47586	338.76	1.36
7	110	14	49672	547.28	49048	274.21	1.26
8		15	50262	503.79	49585	303.56	1.35
9		16	50825	563.98	50002	362.57	1.62
n=400 |B|=291838	**mean**	**15**	**47793.78**	**515.17**	**47092.56**	**282.85**	**1.47**
10	250	55	272843	1277.83	266506	758.96	2.32
11		56	275784	1367.61	267888	797.26	2.86
12		57	278042	1556.14	271119	796.03	2.49
13	260	55	281399	1399.80	274077	802.35	2.6
14		56	283841	1558.39	280072	844.63	2.34
15		57	287848	1634.70	281105	937.42	1.33
16	270	55	290987	1486.89	284865	924.84	2.11
17		56	291350	1567.50	285241	984.16	2.09
18		57	291838	1764.22	285675	934.63	2.12
	mean	**56**	**283777.22**	**1512.56**	**277394.22**	**864.48**	**2.25**

5. CONCLUSION

The delivery of first-aid resources is one of the main components of an operational emergency logistics system after a disaster. This paper deals with a problem of routing of vehicles for first-aid distribution in the event of a humanitarian disaster.

The problem considered here is to determine vehicle routes, subjected to maximum duration constraints, which maximize the number of served beneficiaries who has access to at least one service point. This optimization problem is modeled as a mixed integer linear programming model of the team orienteering problem with overlaps.

To solve the problem, the PBSA and the SA algorithms are developed and tested on a set of numerical examples.

The efficiency and superiority of the PBSA is proven by the number of served beneficiaries for a given set of vehicles subjected to maximum duration constraints. Computing time of both algorithms is reasonable and each of them is acceptable for solving the problem in real time.

Another research direction is a comparison between the algorithms according to parameters different than those considered in this paper, such as the impact of different values of degrees of overlaps among service regions. Additional research opportunity is the usage real data set with larger number of instances.

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SOLUTIONS AND MODELS FOR THE REALIZATION OF THE LAST MILE IN E-COMMERCE LOGISTICS

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Abstract: *Since the day e-commerce has appeared, products can be ordered from home, people don't have to go to shopping centre or wait in a queue, they can simply wait for the moment of home delivery. As information technology improves, customers' needs become greater and more miscellaneous daily and they accept advantages that digital technology brings, for example the experiences of other customers, comparison of product prices, wide assortment etc. The process of shopping starts with the choice of the products, then the product will be delivered and it is accepted or sent back in the end in some cases. In order to satisfy customers' needs, it is necessary to coordinate the realization of order, product demand and the time of delivery. Since logistic service is considered to be the main dimension of quality of business service in the e-commerce, this paper is about solutions and models of the last mile delivery.*

Keywords*: city logistics, last mile, e-commerce, delivery models*

1. INTRODUCTION

Nowadays when needs and demands of all of the products on the marketare greater, bigger need for fulfilling of the customers' wants and needs appeared proportionally. With development of technology, the traditional way of purchase became insufficient for customers. Nowadays customers prefer simpler ways to get the products. The invention of the internet changed their awareness about convenience, speed, price and information about purchase and they count more on the home delivery. Due to enlargement of the urban areas and the number of citizens there, the delivery in the last mile is a huge problem in the cities, for the government and also for the citizens. The delivery to the end user very often represents the shortest phase in the system of the goods, material and cargo distribution, but it is the most complex, the most challenging and the most expensive task considering managing and functioning of supply chains of e-commerce (Gevaers et al., 2009). That is the reason of drawing significant attention in the last decades. According to Goodman (2005), the final delivery of the goods from the distribution centres to the customers is up to 28% of total transport costs. It is in the interest of the user and the service provider that the delivery is as fast, efficient and with

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minimal costs as possible. Home delivery, same day deliveries, time windows, on-time deliveries, alternative pickup locations and real-time tracking are just some of the challenges facing last mile delivery providers. As last mile delivery is one of the main tools of the company for gaining customer loyalty, but also one of the higher costs in the total value of the product, it is necessary to invest effort and conduct research to find adequate solutions and models for this part of the supply chain.

The aim of this paper is to consider the basic characteristics of the realization of the last mile in the logistics of e-commerce and to describe the basic solutions and models of last mile delivery realization. The paper is organized as follows. After the introduction, the the second section describes the basic characteristics of city logistics and last mile delivery in the city area. The third section describes the organization of last mile delivery through four main aspects: location, way, time and speed of delivery and points of consolidation/deconsolidation and transshipment. The fourth section is dedicated to the solutions and models of the realization of the last mile. Finally, concluding remarks and directions of future research are given.

2. BASIC CHARACTERISTICS OF THE LAST MILE DELIVERY

Logistics can be defined as a multidisciplinary science that deals with the tasks of planning, organizing, managing and controlling the flow of goods, materials, cargo, energy, information and persons. One of the most complex logistics systems is related to the supply of urban areas, which deals with city logistics. City logistics includes all movements of goods, materials and cargo to, from and within a certain urban area, all modes and means of transport that pick up or deliver goods, as well as accompanying logistics processes and activities (warehousing, inventory management, packaging, information exchange, routing, reverse logistics, etc.) (Hicks, 1977; Lu & Borbon-Galvez, 2012). In doing so, it is necessary to take into account the traffic environment, congestion, safety, energy saving and environmental protection. City logistics is an area that connects end users and logistics systems, including tasks and decisions at the macro level, across the meso level (urban distribution), to the micro level (last mile logistics) (Figure 1). At the macro level, city logistics refers to the overall flow of vehicles and goods in the city area, encompassing all participants, resources, standards and city policy. At the meso level, city logistics is focused on distribution within urban areas, organization of the city network, infrastructure and logistics services, and includes the inflow of freight traffic into the city and consolidation of cargo. The micro level is the last mile logistics that represents the final stage of urban distribution and thus connects the distribution network with end consumers (Cardenas et al., 2017).

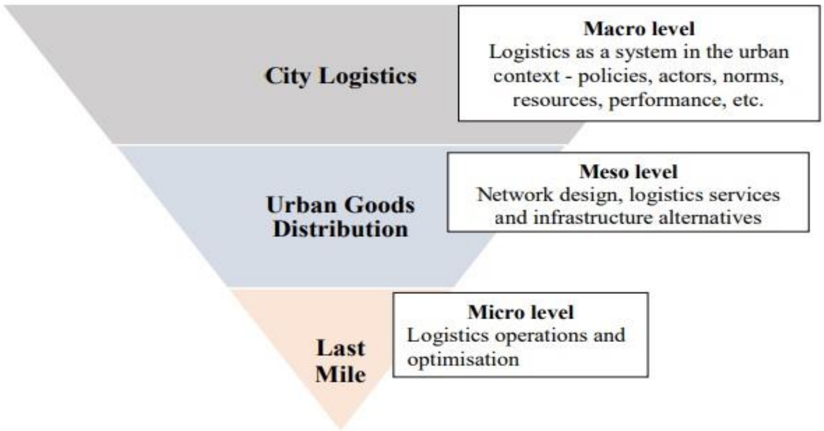

Figure 1. Hierarchical structure of urban freight (Ewedairo, 2019; Cardenas et al., 2017)

Last mile logistics encompasses the processes and activities during delivery from the last transit point of to the final consumer in the supply chain (Lindner, 2011). It also includes the consolidation of cargo as well as the reduction of transport units. Last mile logistics includes delivery, i.e. transport, storage, consolidation, inventory management, sorting, planning, etc. Last mile logistics is characterized by high-frequency distribution of small quantities of goods to end users, usually over short distances. (Anderson et al., 1996). Last mile delivery takes place not only in cities, but also in smaller towns or rural areas, but it is still predominantly developed in urban areas. The last mile is the most inefficient and expensive part of the supply chain and represents a significant problem of urban planning. It is necessary to efficiently and wisely plan the delivery of the last mile, because delays and inefficiency of this part of the supply chain can lead to economic losses for suppliers and end users, but also to traffic congestion and environmental pollution in the urban area.

The distances covered in the last mile can be from a few to a hundred kilometers, with the goal of delivering as quickly, efficiently and cheaply as possible. A special problem is the realization of the last mile in the Central Business District, where various factors must be taken into account - traffic restrictions, permitted types of vehicles, existing infrastructure, traffic organization, time intervals for receiving goods and the like.

The following are the types of last mile delivery systems (Figure 2) (Ewedairo, 2019):

- D2B (Distribution Center to Business) - Delivery of goods from the distribution center/warehouse to the company;
- B2B (Business to Business) - Delivery of goods between companies includes delivery of goods between two logistics centers/warehouses. Deliveries often involve greater distances and the use of larger vans;
- B2C (Business to Consumer) - Delivery of goods from the company to the end users is a delivery that involves the delivery of small quantities of goods but at high frequencies. It can include both larger and smaller distances;
- C2C (Consumer to Consumer) - Delivery of goods between end users is usually transaction of a smaller volume of goods between consumers;

- C2B Consumer to Business) - Delivery of goods from the end user to the companies includes the return of products from the end users to the companies.

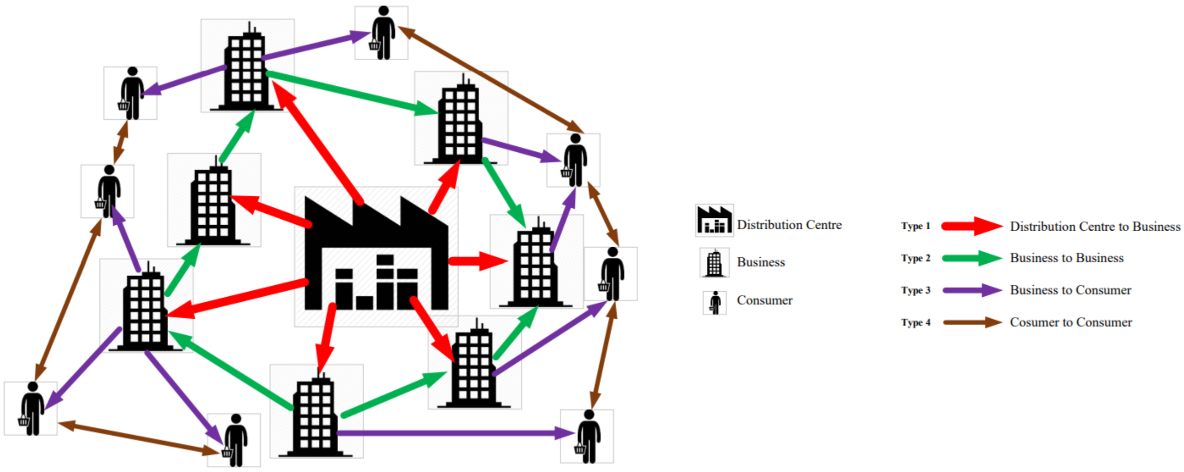

Figure 2. A typology of Last Mile Delivery system (Ewedairo, 2019)

As the significance and complexity of last mile delivery cannot be seen through definition only, several perspectives need to be considered (Ewedairo, 2019):

- Supply chain perspective - one of the key parts of the supply chain is last mile delivery. The supply chain cannot be completed until the goods have been delivered to the end user who started it. In order to maintain the level of customer demand, it is necessary to meet his expectations of both the product and the logistics service. Customer expectations will be met only by coordination of processes and activities in the entire supply chain and cooperation of all participants.
- Cost perspective - The goal of end users as well as distributors in last mile delivery is to minimize costs. Delivery is characterized by: restrictions (city government, infrastructure, transport network, location) that create a certain level of uncertainty for delivery, different levels of interest to be met (city government, end consumer and distributor), frequency of delivery in the last mile, which is so high that all the resources invested in delivering actually are long-term investments. All this is associated with high delivery costs and affects the importance of choosing criteria to minimize costs.
- Spatial perspective - considers last mile delivery as a service within the constraints imposed by the geographical characteristics of pick-up and delivery locations. Some of the spatial factors that can affect delivery are population density, availability and distance of locations, infrastructure system and connectivity. Each of the factors directly affects the time, reliability, flexibility and cost of delivery.
- The perspective of urban planning views the last mile delivery as an essential part of the development and design of urban infrastructure. Effective planning

and design of future construction facilitates the process of movement of people, information and goods.

3. ORGANIZATION OF THE LAST MILE IN E-COMMERCE

In order to understand and present the importance of logistics service for customers in e-commerce supply chains, it is necessary to first define e-commerce. Just as there is no universal definition for city logistics and last mile delivery, it is impossible to view e-commerce in just one definition. From the perspective of communications, e-commerce is the exchange of information, products or services and means of payment via telephone lines, computers or the Internet. From the point of view of end users, e-commerce provides the ability to easily purchase and deliver desired products or services, while from a business process perspective, e-commerce is a tool to increase revenue, sell products and services, while reducing costs and advertising material (Kalakota & Whinston, 1997).

E-commerce makes it much easier to reach the global market for different types of goods and services with flexible communication between manufacturers, suppliers and customers. E-commerce can cover any of the delivery types from Section 2 (D2B, B2B, B2C, C2C, C2B). Advanced Internet-based information technologies have enabled e-commerce users to sell or buy a wide range of products and services. E-commerce has other advantages such as the possibility of purchasing goods that are not sold locally, better price comparison, etc. The main challenge of e-commerce is how to deliver the ordered product to the end user, where there is usually a request for same or next day delivery. In addition, e-commerce has a higher number of product returns compared to traditional commerce (Tadić & Veljović, 2020).

In order to meet the expectations and demand of the end user, adequate last mile delivery is required, which requires complex planning. Due to the demanding nature of last mile delivery, companies usually leave delivery to logistics providers (3PL). A 3PL provider can be defined as a company that manages, controls and performs part or all of a logistics service from shipper to receiver (Hertz & Alfredsson, 2003). Logistics service is not just a product delivery service, but a complex concept that refers to the complete process of e-order realization, and includes activities such as: information, receipt and processing of orders, product packaging, warehousing and inventory, flow consolidation, transport, handling operations, mediation, customs procedures, shipment tracking, last mile delivery, product return from the market, processing and issuance of documents, complaints, etc. The organization of the last mile delivery can be seen through four basic aspects, location, way, time and speed of delivery and points of consolidation/deconsolidation and transshipment.

3.1. Delivery locations

The delivery location does not have to be just a home address. To reduce congestion and increased the efficiency of delivery, numerous contactless delivery solutions have been designed (Marcucci et al., 2020; Lal Das et al., 2018):

- Parcel lockers – Automatic lockers, located near public places (gas stations, bus stations, parking lots, supermarkets) where distributors leave products for storage, then final users pick up them using specific codes. During online shopping, end users choose the location of the locker where they will pick up products, and receive a confirmation by e-mail. This type of delivery became widely used during the Covid-19 pandemic.

- Pickup points – usually are stored authorized to receive packages from e-retailers and deliver them to the consumer. Similarly to parcel lockers, they based on principle of the consolidation goods, and goal of minimizing missed deliveries. These can be gas stations, clothing stores, grocery stores, etc. who rent part of their space to an e-retailers. Pickup points can be gas station, clothing stores which lend their space to e-retailers.
- Reception boxes - locations to pick up packages in front of retailers' stores and warehouses. During online ordering, the end user receives a code with which he can download his order.

3.2. Way of delivery

Some of the most commonly used last-mile delivery methods are (Marcucci et al., 2020; Lal Das et al., 2018):

- Click & Collect concept involves purchasing online and then picking up the goods by the end user at one of the pick-up locations. This distribution channel is used by customers to buy products online and download them in stores when they want. The mentioned sales channel offers customers more flexibility, as they do not have to stay at home and wait for the product to be delivered to their home address.
- Reserve & Collect concept is very similar to the previously described model. The only difference is that customers pay for the products in the store, i.e. when they come to pick up the products they have booked online.
- Try & Buy concept involves ordering goods online, the ability to test the product in one of the stores and then pick up. This model is designed to reduce the return flow of goods. Also, if the end user enters the store, there is a possibility that he will buy more products.
- Crowdshipping concept involves the use of technology to organize a large group of people for the purpose of delivery. In other words, the platform involves hiring ordinary people who are already traveling from point A to point B and who on that occasion pick up the package to deliver to the end user.
- Order online & have the product home delivered is a concept where the customer orders the product online and waits for it to be delivered to the home address. Home delivery is usually the most expensive option. Products can be delivered to end users from logistics centers/warehouses or from stores.

3.3. Delivery time and speed

Deliveries can be performed during the day or night. Deliveries during the day are frequent, but include long delays due to traffic congestion and inability to access shops and customers, but often also due to insufficient demand, which must be aggregated, which is why deliveries are delayed. For these reasons, night deliveries can be performed. Night delivery is most often used together with parcel lockers (Gatta et al., 2019). Night deliveries can reduce mileage, traffic congestion, shorten delivery times and reduce costs. The main disadvantage of night delivery is vehicle noise and unloading operations, so quiet vehicles and staff vigilance during unloading are necessary.

From the aspect of speed, deliveries differ multi-day, next-day, the same-day and instant delivery (Tadić & Veljović, 2021). The speed of delivery depends on a number of factors, but the type of goods and costs are crucial for users (Joerss et al., 2016). Thus, food and time-sensitive goods usually require high speed of delivery, while long-term goods usually do not require.

3.4. Points of consolidation and transshipment

The performing of the last mile delivery may include various intermediate points, i.e. facilities in which the consolidation/deconsolidation of flows or transshipment between different transport modes or means of transport is performed. Various forms of consolidation centers, transshipment terminals, mobile warehouses, etc. can be used for this purpose.

Consolidation centers, managed by a 3PL provider, provide logistics services, including transportation, material handling, warehousing, distribution and order picking. Consolidation centers are facilities in which a certain amount of goods from several suppliers is stored, then sorted, packed to order and delivered to end users, by vehicles intended for urban traffic. The area served by the consolidation center is divided into zones to maximize vehicle capacity utilization and minimize transportation costs and delivery times (Mckinnon et al., 2010).

Transshipment terminals are used to transship goods from one vehicle to another, or from one mode of transport to another, in order to reduce total transport costs, transport unit and optimize the delivery route. The main advantage of using transshipment terminals is that there is no need to store goods, which directly reduces costs. The disadvantage of this solution is the time synchronization between vehicles (Cortes et al., 2010).

The use of mobile warehouses implies the introduction of areas in the central part of the city intended for parking vans and trucks, where they would remain parked, while deliveries to the area are made on foot, handcarts, bicycles, scooters or other alternative vehicles (Munuzuri et al., 2004). The idea stems from the fact that delivery vehicles do not move along congested areas during the peak hour of traffic.

4. LAST MILE REALIZATION MODELS

Authors Winkenbach and Janjevic (2018) defined 10 last mile realization models used by e-retailers based on 5 variables - order lead time (delivery speed), place of order preparation, route organization, intermediate transshipment and product exchange point (place of delivery). These models are described below.

Direct last mile realization to home address, near home or to workplace - This is the most common model of last mile delivery. Orders are prepared in a warehouse or distribution center, or redirected through regional consolidation centers from where they are delivered directly to customers' homes or workplaces. Warehousing operations are managed by an e-retailer or 3PL provider, while the distribution itself can be performed by postal operators, courier, express or parcel services (CEP services). Delivery time may vary from one day to one month depending on product availability.

Last mile realization using automatic lockers - In this model, the delivery process is managed by postal operators, CEP services or the e-retailer himself, but customer orders are not delivered to the home address but to automatic lockers. Amazon and DHL are some of the most well-known companies that use this delivery model.

Last mile realization using pick-up locations - The delivery process is managed by the postal operator or the e-retailer himself, but orders are not delivered to customers' homes or workplaces, but to pick-up points in the city, which are usually found in stores. Package suppliers can enter into cooperation agreements with local stores. In some cases, these agreements include exclusivity clauses, i.e. local stores can receive packages from only one supplier (Winkenbach & Janjevic, 2018). Retail facilities accept agreements, because this type of delivery can provide new customers for them. These locations can also offer additional home delivery at the customer's request.

Last mile realization using consolidation center - In this delivery model, customer orders are routed through a consolidation center managed by a 3PL provider or the e-retailer itself. One example is La Petite Reine in Paris, which manages three consolidation centers, from where last mile delivery is done by electric tricycles (Winkenbach & Janjevic, 2018).

Last mile realization using mobile warehouse - In this delivery model, the city part of the transport is performed with additional reloading in the mobile warehouse. One example of this model is Yamato transport in Japan, which uses a stationary truck as a mobile warehouse near an urban zone, then packages are delivered by hand or electric scooters to end users (Rodrigue, 2015).

Last mile realization using an intermediary transshipment point - This delivery model includes additional transshipment of goods from one mode of transport to another. An example of such a delivery is the concept of “Espace de Livrasion de Prokimite” in France (Gonzales-Feliu et al., 2013). An area near the city has been designated where trucks and delivery vehicles can be parked, and then electric bicycles are delivered to the end users.

Last mile realization with the consolidation and by local provider - This model of delivery involves consolidation in the logistics center of the provider, where stocks of products are kept. Delivery is made by the local provider on the same day as the ordering. One example is Colizen in Paris, which owns consolidation centers where it stores Nespresso machines and then, after an online order, delivers them to the end user on the same day using electric scooters or bicycles (Winkenbach & Janjevic, 2018).

Last mile realization on the same day by optimizing the process - E-retailers offer same-day delivery services, reducing time of delivery. This system includes twenty-four-hour operations with automatic machines for sorting and processing orders in facilities in the immediate vicinity of the user. It does not mean keeping stocks, but optimizing existing capacities and traffic networks.

Last mile realization by pick-up by the user in e-fulfillment logistics centers/warehouses - This delivery model involves personal pick-up of goods by the user, on the same day in e-fulfillment logistics centers. These centers are specialized warehouses near the urban area where e-commerce customer orders are prepared immediately after online ordering, then on the same day the customer comes for the purchased product. They are also called cybermarkets because the products are bought online, but picked up in a warehouse.

Last mile realization using CEP services or crowdshipping network - This model involves delivery to the end user via CEP services or crowdshipping network. As CEP services are often not large enough to make all home deliveries during peak periods, e-retailers organize a group of non-professionals across the platform to deliver goods. For example, in Kenya, taxi drivers can apply to make a delivery for an e-retailer when needed.

5. CONCLUSION

Satisfied users, as the last part in supply chain, are the measure of business success of every company. The biggest challenge of the last mile delivery realization is the increase of online trading. With the rapid development of the cities, considering the present state in the world with the appearance of COVID-19, internet trading has drastically increased. The need of the users for special product assortments, which should be home delivered in the appropriate time has been appeared. Process organization and the realization of delivery to the end user must consider different limits (existing infrastructure, allowed vehicles, time intervals for reception, etc.) in order to plan optimal delivery strategy. In order to perform delivery effectively with the small expenses and the big level of satisfaction and reliability, it is necessary to introduce the particular solutions and models of the last mile delivery.

In this paper the possible solutions of the location, ways, delivery time and speed and points of consolidation/ deconsolidation and transshipment of the goods have been described, as well as ten primary models of last mile delivery. The future research should be referred to an advancement of these models in the order to save the environment, to minimize the use of the vehicles and the traffic congestion with the increase of satisfaction of the end users.

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LAST-MILE DELIVERY (LMD) MODE SELECTION USING A MULTI-CRITERIA DECISION-MAKING APPROACH

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Abstract: *Last-Mile Delivery (LMD) is the final and one of the most demanding steps in urban logistics distribution. In a modern, information society, e-commerce is one of the most significant generators of LMD volumes. Having in mind its exponential growth in recent years, the task to organize efficient LMD is more and more demanding. This paper aims at solving the LMD mode selection problem. Since there are several possibilities considering the LMD in cities around the world, there is a question about which mode to choose in a concrete case. In this paper, a Combined Compromise Solution Method (CoCoSo) is used to select the most appropriate LMD mode in the capital of Serbia - Belgrade. Five possible LMD modes are considered such as Traditional, Cargo Bikes, Public Transport, Electric Vehicles, and Drones. The applicability of the CoCoSo method is demonstrated in an illustrative example, and the experts' opinions are included. The result of the CoCoSo method ranks the alternatives from best to worst.*

Keywords*: last-mile delivery, CoCoSo, transport mode.*

1. INTRODUCTION

Last-Mile Delivery (LMD) is an essential part of city logistics and postal processes. The main aim of the city logistics is organizing, managing, and monitoring the delivery of shipments to the final users in the territory of the city. According to Dablanc (2017), the notion of city logistics is specified as any delivery of services contributing to effectively managing the circulation of goods in cities and providing inventive reactions to customer requirements. Since the customers' demands and expectations are increasing over time, especially in urban areas, the managers of the distribution companies face constantly new problems related to LMD. In addition, globalization, as well as the rapid development of e-commerce, have caused increased transport, especially in urban areas. According to Ranieri et al. (2018), due to globalization and the increased e-commerce activities, products can be acquired everywhere, shipments travel all over the globe and the vast

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majority of the shipments are delivered in cities. World Economic Forum estimates that by 2030 last-mile service in urban areas will increase by 78% (WEF, 2020).

The rapid development of the Internet, as well as online shopping, allows people in both rural and urban areas to move as little as possible and to simply receive their shipments to their address. Here is the need for the organization of logistics activities in the city, which is not an easy task for shipment companies. The reason is simple, cities suffer from traffic congestion, there are too many shipments, different user requirements and expectations, etc. It can also be pointed out that the companies that distribute shipments to end-users are under enormous pressure. Good organization, as well as coordination of all distribution activities, can greatly increase the percentage of satisfied customers, reduce costs, save time and thus be ahead of the competition.

The organization of LMD can be also affected by some other factors, such as pandemic circumstances. For example, when the COVID-19 pandemic started, due to reduced access to physical shops and the lower mobility of consumers, the e-commerce market significantly increased (Figure 1). The year-on-year (YoY) change in the number of online orders illustrates a marked growth with respect to the year 2019. Such huge changes represent a demanding task for postal and logistic companies to deliver the ordered retail goods to customers.

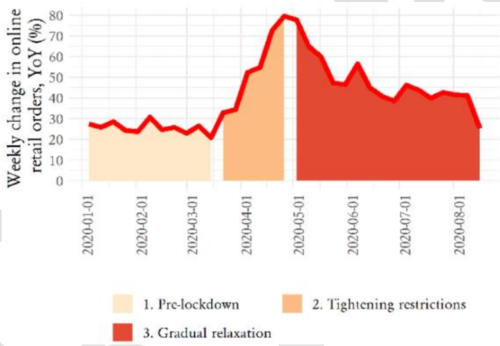

Figure 1. YoY evolution of global e-commerce orders (Source: UPU, 2021)

Previously explained forces managers of the postal and logistics companies to constantly improve the technological process in their companies. One of these issues relates to transport mode selection. In this paper, we consider the LMD mode selection problem in the context of Belgrade, Serbia. We used a Combined Compromise Solution - CoCoSo method (Yazdani and Chatterjee, 2018; Yazdani et al., 2019). The added value of CoCoSo is in combining compromise perspectives with the aim to reconcile conflicting evaluation criteria. At the same time, a selection of LMD mode includes multiple, and often conflicting, performance criteria like time (deprivation), cost, coverage, equity, and security (Ferrer et al., 2018). The five alternatives as possible solutions are considered: Traditional, Cargo Bikes, Public Transport, Electric Vehicles, and Drones. These five alternatives are compared according to six evaluation criteria.

This paper is structured in the following way: Section 2 is the review of the literature based on CoCoSo applications. Section 3 is the description of the methodology. Section 4 is the application of the methodology, an illustrative example in the context of Belgrade, the capital of Serbia. Section 5 offers the managerial implications, while Section 6 gives some concluding remarks.

2. LITERATURE REVIEW

This section presents a summary of the available applications of the CoCoSo method and its extension in various fields. CoCoSo is a relatively new MCDM method with growing popularity among researchers (Figure 2). Since it was introduced by Yazdani and Chatterjee (2018) it has been applied in various fields dealing with the selection of the best alternative under numerous conflicting criteria.

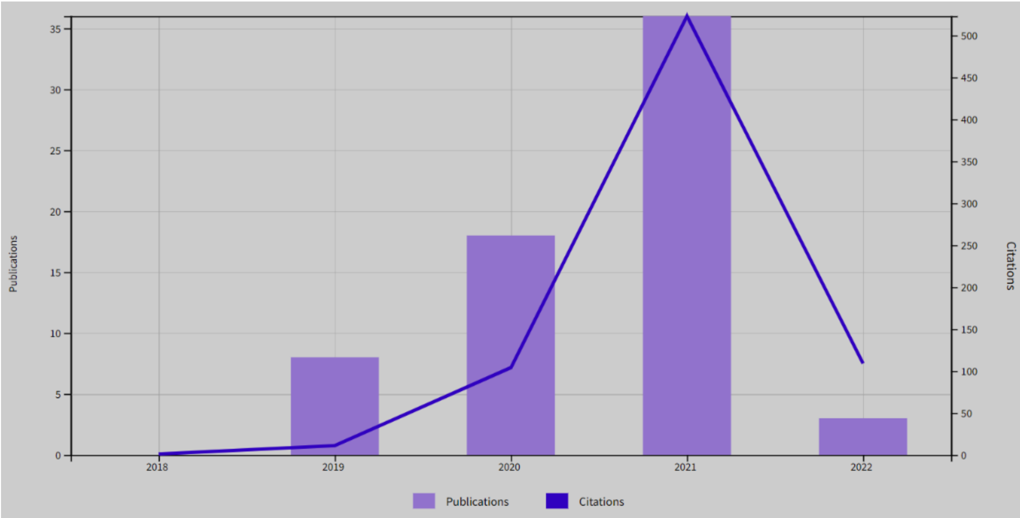

Figure 2. Number of publications and citations of the CoCoSo method (Source: WoS)

For example, Yazdani and Chatterjee (2018) applied this method in the technology selection in the manufacturing industry. Biswas et al. (2019) evaluated and selected electric vehicles. Ecer and Pamučar (2020) evaluated and selected sustainable suppliers. Hashemkhani Zolfani et al. (2020) investigated a temporary hospital location. Ulutaş et al. (2020) searched for the best logistics center location. Peng and Smarandache (2020) evaluated China's rare earth industry security by the CoCoSo. Recently, Popović (2021) applied the CoCoSo in the personnel selection process. Mandal et al. (2022) used the CoCoSo to select a cloud service provider. Turskis et al. (2022) applied the method in the civil engineering industry. The CoCoSo method is also used for LMD mode selection in the case of Pardubice, Czech Republic (Švadlenka et al., 2020).

As may be noticed from the literature review, the application of the CoCoSo method can be found in various fields such as manufacturing, automotive industry, logistics, human resources, civil engineering, etc. Following the recent application for the LMD mode selection problem (Švadlenka et al., 2020), in this paper, the CoCoSo method is used in the case of Belgrade, Serbia. The next section is the elaboration of the CoCoSo method.

3. METHODOLOGY - COMBINED COMPROMISE SOLUTION (COCOSO) METHOD

This section presents a step-by-step method used to solve the Last-Mile Delivery (LMD) mode selection problem. A Combined Compromise Solution (CoCoSo) method is utilized to solve the LMD mode selection problem. This method is proposed by Yazdani and Chatterjee (2018) and belongs to multi-criteria decision-making methods. The CoCoSo method is based on an integrated Simple Additive Weighting (SAW) method and

Exponentially Weighted Product (EWP) model. Yazdani et al. (2019) described the CoCoSo method through the following steps:

Step 1. The initial decision-making matrix with the input data

$$X = \begin{bmatrix} x_{11} & \cdots & x_{12} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{21} & \cdots & x_{22} & \cdots & x_{2n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}, i = 1,2,\ldots,m, j = 1,2,\ldots,\text{n}; \quad (1)$$

Step 2. Normalize the input data

The normalization depends on the type of criteria. if the criterion is a beneficial (B), the following equation for normalization is applied:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, i = 1,2,\ldots,m, j = 1,2,\ldots,\text{n}; \quad (2)$$

If the criterion is a non-beneficial i.e., cost (C), the following equation for normalization is applied:

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, i = 1,2,\ldots,m, j = 1,2,\ldots,\text{n}; \quad (3)$$

Step 3. Obtain the Weighted Sequences S_i and P_i for all alternatives

$$S_i = \sum_{j=1}^{n} (w_j \cdot r_{ij}), i = 1,2,\ldots,m; \quad (4)$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j},\ i = 1,2,\ldots,m; \quad (5)$$

Step 4. Compute the three Total Utility Strategies for all alternatives

The first strategy of total utility (K_{ia}) is the arithmetic mean of the sum of S_i and P_i values:

$$K_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)}, i = 1,2,\ldots,m; \quad (6)$$

The second strategy of total utility (K_{ib}) is the sum of the relative relations S_i and P_i with their worst values:

$$K_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}, i = 1,2,\ldots,m; \quad (7)$$

The third strategy of total utility (K_{ic}) is a balanced compromise of S_i and P_i values:

$$K_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{(\lambda \max_i S_i + (1-\lambda) \max_i P_i)}, 0 \leq \lambda \leq 1; \quad (8)$$

Step 5. Obtain the final ranking of alternatives

The final ranking of the alternatives K_i is calculated by applying Equation (9):

$$K_i = (K_{ia} \cdot K_{ib} \cdot K_{ic})^{\frac{1}{3}} + \frac{1}{3}(K_{ia} + K_{ib} + K_{ic}); \quad (9)$$

4. CASE STUDY

The previously described CoCoSo method is demonstrated in the case of Belgrade, the capital of Serbia. Its position, as well as relief, are illustrated in Figure 3 and Figure 4.

Figure 3. Position of the capital city of Serbia

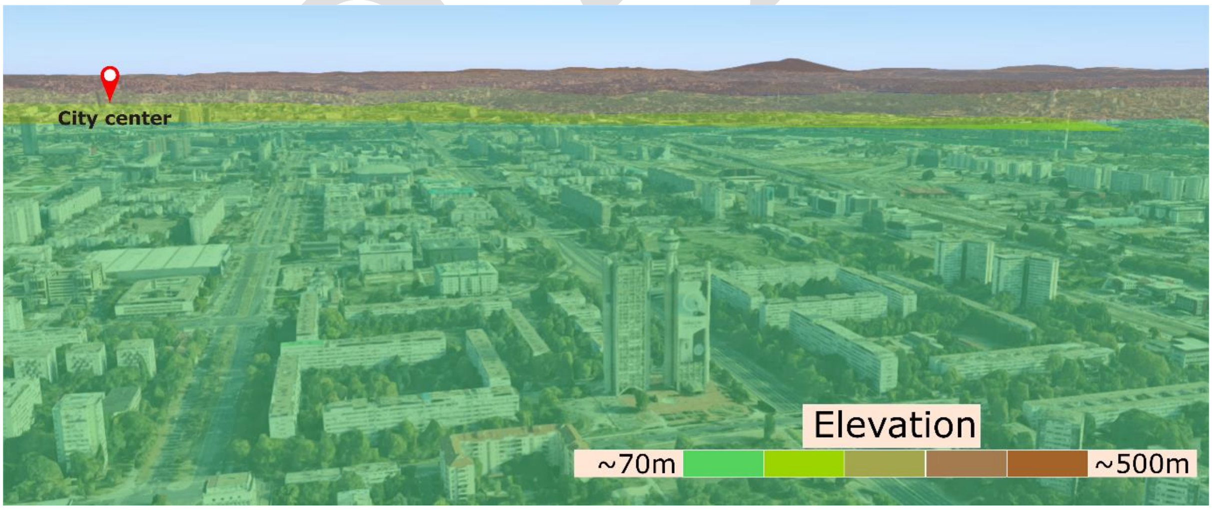

Figure 4. Relief of Belgrade

The city is divided into 17 municipalities. Most of them are located on the southern side of the Danube and Sava rivers. Three municipalities (Zemun, Novi Beograd, and Surčin), are on the northern bank of the Sava. A recent report (Popović, 2020) classifies the air quality in Belgrade as a level III category - excessively polluted air; therefore, certain improvements in the field of transport would be very welcome.

The general formulation of the considered problem of LMD mode selection is presented in Figure 5.

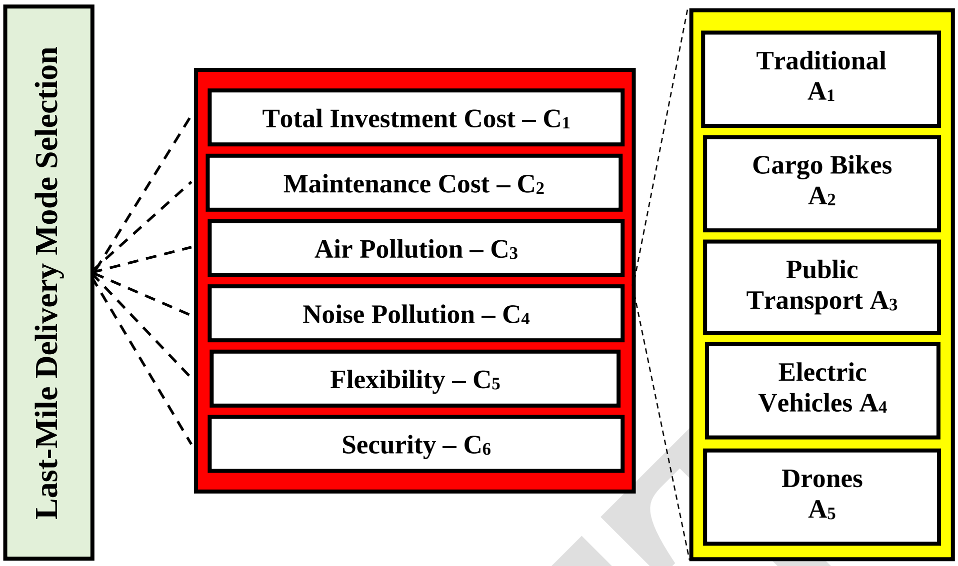

Figure 5. Formulation of the Last-Mile Delivery Problem

In this study, six criteria are taken to determine the best last-mile delivery (LMD) mode. The criteria that are used in this paper belong to the Economic (total investment cost and maintenance cost), Environmental (air pollution and noise pollution), and Technical (flexibility and security) pillars. The criteria are drawn from the previous research on LMD mode selection problem (Ferrer et al., 2018; Švadlenka et al., 2020). The description of each criterion is presented below:

Total Investment Cost (C_1) – the total cost that is necessary to launch the exact last-mile delivery mode. This type of criterion should be minimized. The total investment cost is expressed in Euros, per unit (per car, per drone, etc.)

Maintenance Cost (C_2) – the total cost that is necessary to maintain a possible last-mile delivery mode. This criterion also involves the cost of exploitation, and it's a type of criterion that also should be minimized.

Air Pollution (C_3) – the level of air pollution that should be affected by the determined last-mile delivery mode**.** This criterion is expressed on a scale from 1 to 10, where 1 means worst, while 10 means best air pollution.

Noise Pollution (C_4) – the level of noise that should be emitted by a particular last-mile delivery mode. This one is also expressed on a scale from 1 to 10, where 1 means low, while 10 means high pollution. This criterion should be minimized.

Flexibility (C_5) – the ability of a particular last-mile delivery mode to adapt to possible changes and contingencies. This criterion is expressed on a scale from 1 to 10, where 1 means a low level of flexibility, while 10 means a high level of flexibility. This criterion should be a max type.

Security (C_6) – the level of the last-mile delivery mode protection in terms of shipments security. This criterion is expressed on a scale from 1 to 10, where 1 means a low-security level, while 10 means a high-security level. This criterion should be a max type.

Five alternatives should be considered to find the best last-mile delivery mode solution.

Alternative 1 (A_1) – Traditional Last-Mile Delivery mode - This is the current LMD mode that is already being used in the territory of Belgrade.

Alternative 2 (A_2) – Cargo Bikes - Cargo Bikes are a relatively new solution for the LMD mode, and this mode should be suitable especially in urban areas since it is easier not only to ride into the city center but also to park, without any air pollution and noise emissions for the environment.

Alternative 3 (A_3) – Public Transport – The idea of including public transport as an LMD solution came from the experts the authors discussed regarding the topic. Public transport should be used as an LMD solution only to deliver items to inner-city hubs in the city since there are not any frequencies of travelers during the night hours.

Alternative 4 (A_4) – Electric Vehicles – This LMD solution is considered the possible one since there are no emissions on a large scale, air and noise pollution are minimized and the effect should be positive according to experts.

Alternative 5 (A_5) – Drones – This alternative is also considered as a possible LMD solution.

To evaluate the alternatives according to the established criteria, the expert's opinions are included in a decision-making process. The initial decision-making matrix is fulfilled by the experts. The information about experts is given in Table 1.

Table 1. The information about the experts

Expert	*Gender*	*Qualifications*	*Experience*
Expert 1	*Female*	*Ph.D.*	*Associate professor at the Postal Traffic Department with 15 years of experience*
Expert 2	*Male*	*Ph.D.*	*Associate professor at the Postal Traffic Department with 16 years of experience*
Expert 3	*Male*	*Ph.D.*	*Full professor at the Postal and Logistics Department with 19 years of experience*

The initial decision-making matrix is formulated and presented in Table 2.

Table 2. Initial decision-making matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0	1500	10	9	0	5
A_2	900	60	0	2	9	10
A_3	0	500	8	8	7	4
A_4	33000	50	0	8	9	10
A_5	3000	110	0	9	3	2

The normalization of the input data is given in Table 3. The obtained Weighted Sequences *Si* and *Pi* for each alternative, the total utility strategies and the final rank are presented respectively in Table 4, Table 5, and Figure 6.

When the CoCoSo method is applied, the following rank is obtained: the highest preference is assigned to Cargo Bikes (0.9529), followed by Public Transport (0.7903), Electric Vehicles (0.7247), Drones (0.6127), and Traditional one (0.3131), respectively.

Table 3. Normalization of the Input Data

	C_1	C_2	C_3	C_4	C_5	C_6
A1	*1.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.3750*
A2	*0.9727*	*0.9931*	*1.0000*	*1.0000*	*1.0000*	*1.0000*
A3	*1.0000*	*0.6897*	*0.2000*	*0.1429*	*0.7778*	*0.2500*
A4	*0.0000*	*1.0000*	*1.0000*	*0.1429*	*1.0000*	*1.0000*
A5	*0.9091*	*0.9586*	*1.0000*	*0.0000*	*0.3333*	*0.0000*
Weights	*0.3500*	*0.1700*	*0.1000*	*0.0900*	*0.0400*	*0.2500*

Table 4. Obtained Weighted Sequences Si and Pi for each alternative

	C_1	C_2	C_3	C_4	C_5	C_6	***Si***	***Pi***	***SiPi***
A1	*0.3500*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0938*	*0.4438*	*1.7825*	*2.2263*
A2	*0.3405*	*0.1688*	*0.1000*	*0.0900*	*0.0400*	*0.2500*	*0.9893*	*5.9892*	*6.9785*
A3	*0.3500*	*0.1172*	*0.0200*	*0.0129*	*0.0311*	*0.0625*	*0.5937*	*5.3266*	*5.9203*
A4	*0.0000*	*0.1700*	*0.1000*	*0.0129*	*0.0400*	*0.2500*	*0.5729*	*4.8393*	*5.4122*
A5	*0.3182*	*0.1630*	*0.1000*	*0.0000*	*0.0133*	*0.0000*	*0.5945*	*3.9170*	*4.5115*
						min	*0.4438*	*1.7825*	*25.0488*
						max	*0.9893*	*5.9892*	

Table 5. Total Utility Strategies for each alternative and final rank

Kia	***Kib***	***Kic***	***Rank***	***Kib norm***
0.0889	*2.0000*	*0.3190*	*0.3131*	*0.1028*
0.2786	*5.5893*	*1.0000*	*0.9529*	*0.2872*
0.2364	*4.3261*	*0.8484*	*0.7903*	*0.2223*
0.2161	*4.0058*	*0.7756*	*0.7247*	*0.2059*
0.1801	*3.5371*	*0.6465*	*0.6127*	*0.1818*

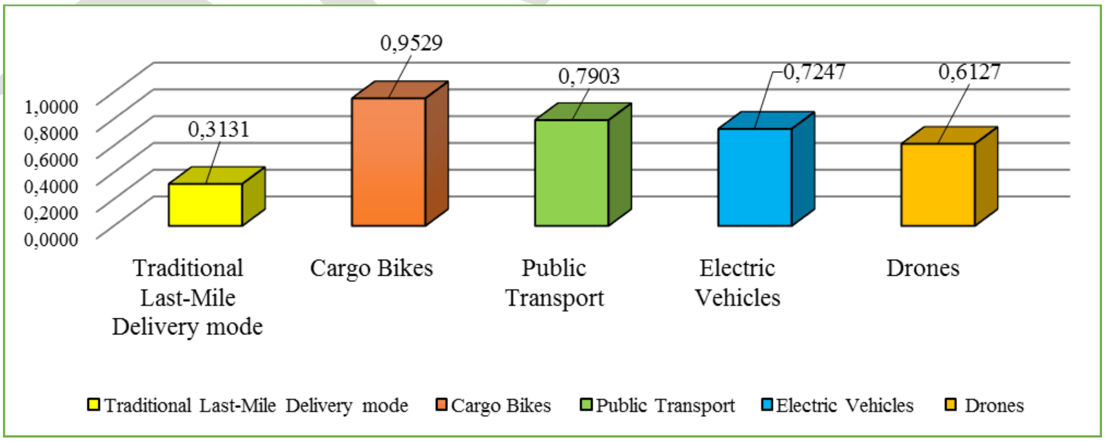

Figure 6. Final Ranking Alternatives

5. MANAGERIAL IMPLICATIONS

In city logistics, the last-mile delivery should be one of the most essential factors to achieve a high level of customer satisfaction. The quality of the last-mile delivery in cities depends on the appropriate LMD mode. In this regard, the municipalities should carefully monitor and assess the best last-mile delivery solutions, having this business more effective and sustainable in this way. Since there are numerous new LMD solutions in the market, it is essential to apply the best one. Without using some of the multi-criteria decision-making techniques, the problem of last-mile delivery mode selection can be considered harder and more uncertain to solve. It may badly affect not only the postal companies but also the final customers who are the most essential part of the last-mile delivery chain. This paper presented a possible approach for ranking the LMD solutions, and the results indicate the cargo bikes as the best solution for the Belgrade case.

6. CONCLUSION

This paper solved the LMD mode selection in Belgrade by applying the CoCoSo method. The five alternatives as possible solutions were considered and were compared according to six evaluation criteria. The results of the CoCoSo method indicate that the Cargo bikes are identified as the best possible alternative for Belgrade with a preference of 0.9529, followed by Public Transport (0.7903), Electric Vehicles (0.7247), Drones (0.6127), and Traditional mode (0.3131), respectively.

Cargo Bikes are becoming more and more popular in the city logistics field and have the potential for the future development of the postal traffic (Ali et al., 2022). The Bikes are flexible, without emissions, and can serve the city centers of urban areas more easily (Švadlenka et al., 2020). Public transport and electric vehicles should be considered in the future as a good choice for the LMD in urban areas, therefore special attention should be placed on those modes (Lazarević and Dobrodolac, 2020). When it comes to drones operating in Belgrade, there is still space to prepare the infrastructure and policies on a national level to be adopted to this model, according to experts' opinions. As a direction for future research, a more comprehensive methodological approach can be applied providing more insightful managerial implications.

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SOLVING THE VEHICLE ROUTING PROBLEM WITH HETEROGENEOUS VEHICLES BY THE BEE COLONY OPZIMIZATION METAHEURISTIC

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Abstract: In this paper, we consider the vehicle routing problem with heterogeneous vehicles. For this problem, we propose the Bee Colony Optimization metaheuristic. We tested our method on one benchmark example. Obtained results show that the metaheuristic significantly outperforms previous solutions given in the literature.

***Keywords**: Vehicle routing problem, heterogeneous vehicles, Bee Colony Optimization*

1. INTRODUCTION

The vehicle routing problem (VRP) is one of the most studied combinatorial optimization problems. The main goal is to find the best vehicle routes in the network while minimizing one or more criteria. This problem was set up for a first time by Dantzig and Ramser (1959), while the first algorithm for solving the routing problems was posted by Clarke and Wright (1964). Till today many papers have been written dealing with the vehicle routing problem. During the time, the VRP has received numerous extensions. Some of these modifications are: the VRP with time windows (VRPTW), the VRP with simultaneous pickup and delivery (VRPSPD), the electric vehicle routing problem (E-VRP), etc.

This paper is considering a variant of the VRP problem which refers to routing the vehicles with different load capacity and volume. This variant is known as the vehicle routing problem with heterogeneous vehicles or as the heterogeneous fleet vehicle routing problem (HFVRP). The HFVRP problem was first defined and solved in the paper Golden et al. (1984). Li et al. (2007) developed a new variant of algorithm called record-to-record travel algorithm. This algorithm solves the standard VRP that considers a heterogeneous fleet. After Golden et al. (1984), the mentioned problem was solved by applying Tabu search metaheuristic in the papers Semet and Taillard (1993),Rochat and Semet (1994), Brandao (2011), etc. Prins (2002) developed a heuristic algorithm for solving the HFVRP problem. Primary goal of this algorithm was minimizing costs and the secondary goal was

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the minimizing of number of vehicles used. This heuristic can easily face with various limitations and provides good starting solutions for using Tabu search metaheuristic.

Belmecheri et al. (2009) solved the problem called Heterogeneous Fleet VRPMB with time windows. They suggested the formula of integer linear programming and the Ant colony optimization algorithm (ACO). In the paper Ky Phuc and Phuong Thao (2021) the Ant colony optimization algorithm was proposed for solving the problem of routing multiple trucks and multiple delivery vehicles with a time frame and heterogeneous fleets. The problem of profitable heterogeneous vehicle routing problem with cross-docking was solving in the paper Baniamerian et al. (2019). They proposed a new hybrid metaheuristic algorithm based on a modified Variable neighborhood search with four shaking and two neighborhood structures and a Genetic algorithm was introduced to solve major problems.

By reviewing the literature, it can be concluded that the Bee Colony Optimization (BCO) metaheuristics has not been used to solve the VRP with heterogeneous fleet. So, this paper presents for the first time BCO metaheuristics for solving mentioned problem, the algorithm was tested and the obtained results are compared with the results from the paper of Sanz and Gomez (2013) who used Tabu search metaheuristic.

2. PROBLEM DESCRIPTION

We consider the vehicle routing problem where the customers have demands that are characterized by weight and volume. A company's fleet consists of the heterogeneous vehicles. Each vehicle has weight and volume capacities, and these capacities cannot be exceeded. There is just one depot at the transport network. All routes have to begin and end in that depot. Each customer should be served by just one vehicle. The aim is to find a set of routes in the way to minimize the total cost.

In this paper we calculate the total cost in the objective function in the same way as Sanz and Gomez (2013):

$$F = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{m} c_{ij} \, x_{ijk} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{m} ev_k \, d_{ij} x_{ijk} \qquad (1)$$

where are:

n – the total number of nodes (the depot is the node 0 and the customers are the nodes from 1 to n),

c_{ij}- the cost for traveling from the node (customer or depot) i to the node j,

x_{ijk}- the binary decision that takes 1 if vehicle k after node i goes to the node j, and 0 otherwise,

d_{ij}- the distance from the node i to the node j,

ev_k – cost efficiency coefficient of the vehicle k.

3. BEE COLONY OPTIMIZATION

Bee Colony Optimization (BCO) is a metaheuristic proposed by Lučić and Teodorović (2001). This algorithm is based on the way how bees collect the nectar in the nature. The artificial bees try in a similar way to search the solution space of the considered combinatorial optimization problem. Up to now, this approach was used as the solution technique for many problems. Teodorović et al. (2021) gave a broad survey of the BCO applications in transport and traffic engineering.

There are two versions of this algorithm: the constructive (BCOc) and improvement version (BCOi). In the constructive version of the algorithm bees in each iteration start with the empty solution. During the iteration bees build their solutions. In the improvement version of the algorithm at the beginning of iterations bees have the same complete solution. Within iteration the bees try to improve that solution making small modifications.

In this paper, we have used the constructive version of the algorithm. The pseudo-code of this version of the algorithm can be given in the following way:

```
1.   do
2.      An empty solution is assigned to each bee.
3.      fori = 1 to the number of passes
4.         forj = 1 to the number of moves
5.            forb = 1 to the number of bees
6.               Evaluate all possible moves of the bee b.
7.               Choose one move of the bee b using the roulette wheel.
8.            nextb
9.         nextj
10.        forb = 1 to the number of bees
11.           Evaluate partial solution of the bee b.
12.        nextb
13.        Normalize quality of generated partial solutions.
14.        For each bee determine will it stay loyal to generated
           solution or not.
15.        forb = 1 to the number of bees
16.           If the bee b is not loyal to its solution, determine one loyal
              bee that the bee b will follow.
17.        nextb
18.     nexti
19.     Evaluate solutions of all bees.
20.  while stopping criteria is not satisfied
21.  Select the best generated solution.
```

An iteration of the algorithm consists of the steps 2 - 20 of the pseudo-code. Mainly the stopping criteria of the algorithm are the number of iterations and CPU time. The parameters of the BCO algorithm are: B - the number of the bees, NP – the number of passes and NM – the number of moves.

Steps 4 - 9 of the pseudo-code are known as forward pass, while steps 10 - 17 are the backward pass. Within the forward pass bees build their solutions, while in the backward pass bees compare their solutions and make loyalty decisions. When the bee is loyal to its solution, it continues to build that solution. Otherwise, if the bee is not loyal to its solution, it will select one of the loyal bees in order to follow it. That means, the bee, which is not loyal to its solution, will accept partial solution of the selected bee (which is loyal to its solution). Generally, in that way the bees with poor solutions most probably will decide to follow the other bees with better solutions.

In the considered problem we define that the number of moves in one forward pass should be determined at the beginning of each iteration. We define that the number of moves (NM) should be selected in the random manner between 1 and 5 ($NM = random[1,5]$).

Taking into consideration the total number of customers/nodes (let us denote this with n) and the number of move (NM) we can calculate the number of forward and backward passes (NP) in the following way:

$$NP = \left\lceil \frac{n}{NM} \right\rceil \tag{2}$$

In each forward pass, from 1st to $(NP-1)$th, the bees have to make NM moves, and in the last forward pass they have to make $n - NM \cdot (NP-1)$ moves.

In one move a bee must assign one customer to the one of the available vehicles. The customer could be assigned to the vehicle so as not to exceed the capacity constraints. When the customer is assigned to the vehicle, it will be put at the end of the vehicle's route. For example, if the vehicle has the current route (depot - 3 - 5 - 2), and the customer 7 is assigned to it, then the new route will be (depot - 3 - 5 - 2 - 7).

The customer j will be assigned to the vehicle k with the probability:

$$p_{jk} = \frac{\frac{1}{ev_k \, d_{ln(k),j}}}{\sum_{i \in N_b} \sum_{s \in K_i} \frac{1}{ev_s \, d_{ln(s),i}}} \tag{3}$$

where are:

ev_k – the efficiency coefficient of the vehicle k,

$ln(k)$ – the last node in the route of the vehicle k,

$d_{ln(k),j}$ – the distance between the last node (customer) in the route of the vehicle k and the customer j,

N_b – the set of customers (nodes) that is not yet assigned to any vehicles,

K_i – the set of vehicles to which customer i could be assign (taking into consideration vehicle capacity constraint)

ev_s – the efficiency coefficient of the vehicle s,

$ln(s)$ – the last node in the route of the vehicle s,

$d_{ln(s),i}$ – the distance between the last node (customer) in the route of the vehicle s and the customer i.

When all bees perform a predefined number of the forward passes and moves, all customers should be assigned to the vehicles. Taking into consideration that all vehicles have to return at the depot, when they finish last delivery, we have to add the depot at the end of each vehicle route.

In the considered problem we have to minimize the objective function (1). According to that, in the 13th step of the backward pass, we normalize the quality of partial solution of the bee b in the following way:

$$O_b = \frac{F_{max} - F_b}{F_{max} - F_{min}} \tag{4}$$

where are:

F_b – a quality of the partial solution generated by the bee b,

F_{max} – a maximal value of all F_b : $F_{max} = \max\limits_{b=1,\cdots,B}\{F_b\}$,

F_{min} – a minimal value of all F_b: $F_{min} = \min\limits_{b=1,\cdots,B}\{F_b\}$.

The probability that the bee b will stay loyal to its solution can be calculated in the following way:

$$p_b = e^{\frac{-(O_{max} - O_b)}{u}} \tag{5}$$

where are:

O_{max} - a maximal normalized value: $O_{max} = \max\limits_{b=1,\cdots,B}\{O_b\}$

u – a current number of the forward pass.

Another very popular equation for the probability p_b is:

$$p_b = e^{-(O_{max} - O_b)} \tag{6}$$

To make a decision will bee b stay loyal to its solution, or not, we generate a random number,γ. The loyalty decision will be made in the following way: if $\gamma \leq p_b$ then the bee will stay loyal to its solution, otherwise it will not. The bees who's decided to stay loyal to its solutions are recruiters.

The bees who's decided not to stay loyal to its solution, have to make a decision to follow one of the recruiter bees. The probability that the bee, which decided not to stay loyal to its solution, will follow the recruiter bee r calculates in the following way:

$$p_r = \frac{O_r}{\sum_{k \in R} O_k} \tag{7}$$

where are:

O_r – a normalized value of the bee's r partial solution quality,

R – a set of the recruiter bees.

4. RESULTS

This chapter presents the comparison of the results of solving the HVRP given in Sanz and Gomez (2013) using Tabu search metaheuristic and using our BCO metaheuristic. A company that distributes foods in Querétaro, Mexico was used as study case. The company distributes a variety of foods in terms of weight and volume, and in addition, some types of food require a temperature regime. The company has a fleet of 3 vehicles, which differ in load capacity, volume and efficiency. The characteristics of each of the vehicles are shown in Table 1. Vehicle efficiency is a characteristic that can take values between 0 and 1, and is measured in relation to the energy consumption of that vehicle and maintenance costs. Vehicles with efficiency of 1 represent vehicles with ideal efficiency.

Table 1. Vehicle's efficiency, weight and volume capacity (Sanz and Gomez (2013))

Concept	Vehicle		
	1	2	3
Weights capacity (kg)	500	200	75
Volume capacity (m^3)	2.5	0.8	0.2
Efficiency	0.55	0.65	0.95

Table 2 shows the location of customers and their demands in terms of weight and volume of required food. The location of the clients is presented in the form of *x* and *y* coordinates, where it should be noted that all vehicles start from the depot with coordinates (0,0). We denote the depot as the node 0.

It should also be noted that the distance between two nodes is calculated using the Manhattan distance equation: $d(i,j) = |x_i - x_j| + |y_i - y_j|$.

Table 2. Customer's location, orders weight and volume (Sanz and Gomez (2013))

Customer *i*	x_i - coordinate	y_i - coordinate	Order weight [kg]	Order volume [m^3]
1	-2.1	-5.2	2.2	0.06
2	-3.1	-6.2	4.5	0.11
3	-8.8	-18.6	10.9	0.14
4	2.6	-25.2	12.2	0.19
5	0.8	-13.5	2.5	0.05
6	-1.1	-10.5	14.3	0.22
7	-1.2	-32.3	3.8	0.08
8	-8.5	-18.8	5.8	0.06
9	1.7	-21.2	4.4	0.09
10	0.5	-13.3	1.5	0.02
11	-3	-6.5	8.5	0.23
12	-0.9	-35.2	19.7	0.29
13	-8.3	-18.2	9.7	0.18
14	1.5	-20.7	4	0.19
15	10.3	-30.5	5.5	0.14
16	0.7	-14.6	6.2	0.12
17	-0.8	-30.2	4.9	0.6
18	-0.5	-12.8	12.5	0.29
19	2.8	-24.3	3.2	0.06
20	-0.3	-6.5	5.5	0.19

The existing routes used by the company for each vehicle in the fleet are generated using a typical assignment problem. These routes are shown in Table 3 as typical solution (Sanz and Gomez, 2013). The table also shows the set of routes obtained by Tabu search algorithm (Sanz and Gomez, 2013). The qualities of both solutions are given in the last column of the table.

Table 3. The vehicle routes proposed by Sanz and Gomez (2013)

Solution	Vehicle	Routing assignment	Objective function
Typical	1	0-16-10-18-13-3-14-9-19-4-17-7-12-15-0	142.33
	2	0-11-2-20-6-0	
	3	0-1-5-8-0	
Tabu search	1	0-18-16-14-19-4-17-7-12-15-8-3-13-0	111.4
	2	0-9-5-10-6-11-2-1-0	
	3	0-20-0	

We applied the BCOc algorithm on the same example. The algorithm was implemented in Java programming language, using Appach NetBeans 13 editor. All tests were made in the desktop computer with the following performances: AMD Ryzen 7 3800 X with 32 GB of RAM memory, operating system: Ubuntu 21.10.

We made two tests of the BCOc algorithm. The difference between them is in the expression how the probability for the loyalty decision is calculated. In the first test we used the equation (5), and in the second test we used the equation (6).

In both tests we used the CPU time as the stopping criteria. We provided results for three different values of the CPU time (0.5, 1 and 2 minutes), and for three values of the number of bees (10, 15 and 20 bees). For each of these 9 options we did 5 runs of the algorithm. The obtained results are given in Tables 4 and 5.

In the first test the best solution has the objective function value 93.96. This solution was obtained with 15 bees and 1 minute of the allowed CPU time. The worst solution has the objective function value 98.27 (obtained with 15 bees and 0.5 minute of the CPU time). The best average objective function value, 95.19, was obtained with 10 bees and 2 minutes.

Table 4. The BCOc algorithm results when equation (5) is used

Run	10 bees			15 bees			20 beeswhen equation (5) is used		
	CPU time			CPU time			CPU time		
	0.5 min	1 min	2 min	0.5 min	1 min	2 min	0.5 min	1 min	2 min
1	97.65	95.94	94.4	96.66	95.61	96.38	96.61	94.64	96.95
2	97.1	97.22	95.48	98.27	95.61	94.73	95.83	96.88	94.88
3	95.15	96.6	95.43	97.15	97.82	96.42	94.62	96.9	95.19
4	95.81	95.72	94.86	97.69	97.08	96.95	98.16	97.15	96.18
5	94.73	97.22	95.78	96.22	93.96	96.03	94.99	96.31	96.16
Min	94.73	95.72	94.4	96.22	**93.96**	94.73	94.62	94.64	94.88
Max	97.65	97.22	95.78	**98.27**	97.82	96.95	98.16	97.15	96.95
Average	96.09	96.54	**95.19**	97.20	96.02	96.10	96.04	96.38	95.87

According to the results obtained with the BCOc algorithm when equation (6) is used, it can be noticed that the best solution has the objective function value 92.75. This solution was obtained for the two set of the parameters (20 bees and 1 minute of the CPU time, 20 bees and 2 minutes of the CPU time). The worst solution has the objective function value 95.54 and it was obtained for 20 bees and 0.5 minute of the CPU time. The best average objective function value, 93.34, was obtained for 10 bees and 2 minutes of the CPU time.

Table 5. The BCOc algorithm results when equation (6) is used

Run	10 bees			15 bees			20 bees		
	CPU time			CPU time			CPU time		
	0.5 min	1 min	2 min	0.5 min	1 min	2 min	0.5 min	1 min	2 min
1	94.75	92.97	93.41	94.75	94.99	93.41	95.54	94.71	93.3
2	94.69	93.69	93.47	93.85	93.36	93.14	94.53	93.74	93.74
3	93.41	93.3	93.41	94.25	94.88	94.18	93.36	94.07	93.3
4	94.69	93.69	93.47	93.69	93.8	92.97	94.73	92.75	92.75
5	94.77	94.31	92.92	94.82	93.96	93.3	94.44	93.85	93.96
Min	93.41	92.97	92.92	93.69	93.36	92.97	93.36	**92.75**	**92.75**
Max	94.77	94.31	93.47	94.82	94.99	94.18	**95.54**	94.71	93.96
Average	94.46	93.59	**93.34**	94.27	94.20	93.40	94.52	93.82	93.41

Among all generated solution the best one is with the objective function value 92.75. This solution is given in Table 6. The weight of the goods on the first route is 106.8 kg and the volume is 2.5 m^3. The second route has the total weight of the goods 29.5 kg and the volume 0.62 m^3. The third route has 5.5 kg and 0.19 m^3 of the goods. It can be noticed that this solution has much better objective function value than the best solutions given by Sanz and Gomez (2013). The relative differences are:

– from the typical solution: $\frac{\mathbf{142.33-92.75}}{\mathbf{142.33}} \cdot \mathbf{100}\ \% = \mathbf{34.83}\ \%$

– from the Tabu search solution: $\frac{\mathbf{111.4-92.75}}{\mathbf{111.4}} \cdot \mathbf{100}\ \% = \mathbf{16.74}\ \%$.

Table 6. The best obtained solution using BCOc

Route 1	0 – 10 – 5 – 16 – 13 – 3 – 8 – 14 – 9 – 19 – 4 – 15 – 7 – 12 – 17 – 18 – 0
Route 2	0 – 6 – 11 – 2 – 1 – 0
Route 3	0 – 20 – 0

5. CONCLUSION

The vehicle routing problem is very important transportation engineering problem. This problem belongs to the group of hard combinatorial optimization problems. To solve this problem researcher mainly use heuristic and metaheuristic algorithms.

In this paper we considered the vehicle routing problem with the heterogeneous vehicles. We applied the constructive version of the Bee Colony Optimization (BCOc) metaheuristic. The developed algorithm was tested on the example given by Sanz and Gomez (2013). This example is from the Querétaro, city in Mexico, and it includes 20 customers. The best obtained solution by the BCOc algorithm is significantly better than the solutions given by Sanz and Gomez (2013). In the future research, the proposed algorithmshould be tested on more examples and compared with other approaches.

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A DISCRETE SYMBIOTIC ORGANISMS SEARCH BASED 2-OPT ALGORITHM FOR TRAVELING SALESMAN PROBLEM

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Abstract: *The traveling salesman problem (TSP) is a well-known combinatorial optimization problem. To address TSP, many exact, heuristic, and metaheuristic algorithms have been developed. In this paper, we have proposed a discrete symbiotic organisms search (DSOS) based 2-OPT algorithm for TSP, named DSOS+2-OPT. The proposed DSOS+2-OPT algorithm is implemented in Matlab environment and tested on symmetric instances from TSPLIB. The overall results demonstrate that the proposed DSOS+2-OPT algorithm offer promising results, with the potential for further improvement, particularly in local search domain.*

Keywords*: Discrete symbiotic organisms search algorithm, 2-OPT algorithm, Traveling salesman problem.*

1. INTRODUCTION

The traveling salesman problem (TSP) is a combinatorial optimization problem in the fields of computer sciences, operation research, and logistics and transportation. The problem is to find the shortest tour that passes through a set of *n* vertices so that each vertex is visited exactly once. In logistics and transportation, the vertices are represented as cities (Ilin et al., 2020). TSP belongs to the class of NP-hard problems, in which optimal solution to the problem cannot be obtained within a reasonable computational time for large size problems. To address TSP, many exact, heuristic, and metaheuristic algorithms have been developed. In this paper, we have explored the use of a recently proposed metaheuristic algorithm, named symbiotic organisms search (SOS) algorithm for TSP.

The SOS algorithm simulates the interactive behavior noticed between organisms in nature. Symbiosis is derived from the Greek word for ‘‘living together’’. De Bary first used the term in 1878 to describe the cohabitation behavior of different organisms (Sapp, 1994). The most common symbiotic relationships found in nature are mutualism, commensalism, and parasitism. Mutualism denotes a symbiotic relationship between two different species in which both benefit. Commensalism is a symbiotic relationship between two different species in which one benefits and the other is unaffected or neutral. Parasitism is a symbiotic relationship between two different species in which one benefits

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and the other is actively harmed (Cheng and Prayogo, 2014). Initially, the SOS algorithm has been developed to solve numerical optimization over a continuous search space. However, the SOS algorithm can be adapted for discrete optimization problems as well. Several recent papers have developed different discrete symbiotic organisms search (DSOS) algorithms for solving the TSP (Ezugwu and Adewumi, 2017; Wang et al., 2019). In this paper, we have developed and implemented basic version of DSOS algorithm in Matlab environment. In order to improve the search capabilities, 2-OPT algorithm is used each time an improved organism is found during the search.

The rest of the paper is organized in the following way. Section 2 explains the SOS algorithm in detail and Section 3 explains the main steps in the DSOS+2-OPT algorithm. Experimental results and discussion are presented in Section 4, and finally, Section 5 provides concluding remarks.

2. A SYMBIOTIC ORGANISMS SEARCH ALGORITHM

The SOS algorithm is a new metaheuristic algorithm that was inspired by the symbiosis commonly found between organisms in nature (Figure 1). Symbiotic relationships may help organisms to adapt to changes in their environment. The adaptation is reflected through increased fitness and probability of survival. Therefore, organisms should benefit from symbiosis in the long run.

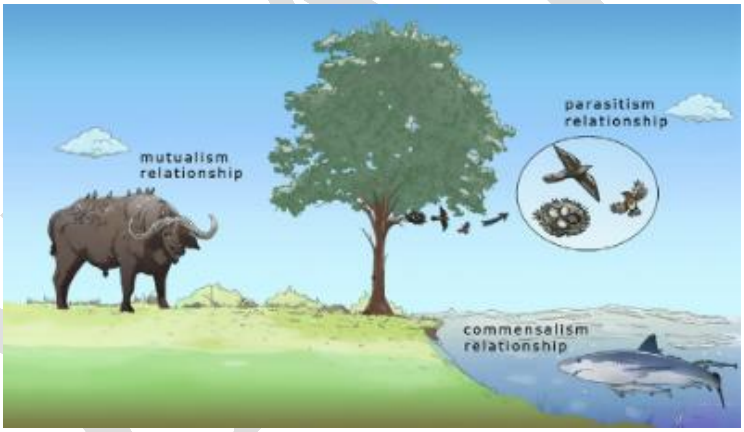

Figure 1. An example of symbiotic relationships in nature (Cheng and Prayogo, 2014)

The SOS algorithm belongs to the group of population-based metaheuristic algorithms. The algorithm has the following characteristics: (1) the SOS uses a population of organisms, which consist of many candidate solutions, examined by the algorithm in a step by step sequence of solutions vector with the hope to approach the global solution over the problem search space; (2) the SOS is also equipped with some kind of special operators that uses the candidate solutions to guide the search process; (3) a selection mechanism is adopted by the algorithm so as to preserve the iteration best solutions; (4) the performance of the algorithm is somewhat dependents on the proper setting of the algorithm's control parameters such as the organisms population size and maximum number of evaluations (Cheng et al., 2015).

The basic steps of SOS algorithm are presented in Figure 2. The main steps are: (1) initialization, (2) symbiotic phase (mutualism, commensalism, and parasitism), and (3) identification of the best solution found. The main parameters in the SOS are termination criteria, named *MaxIter* and number of organisms, named *eco_size*. The computational results are highly dependent on those two parameters.

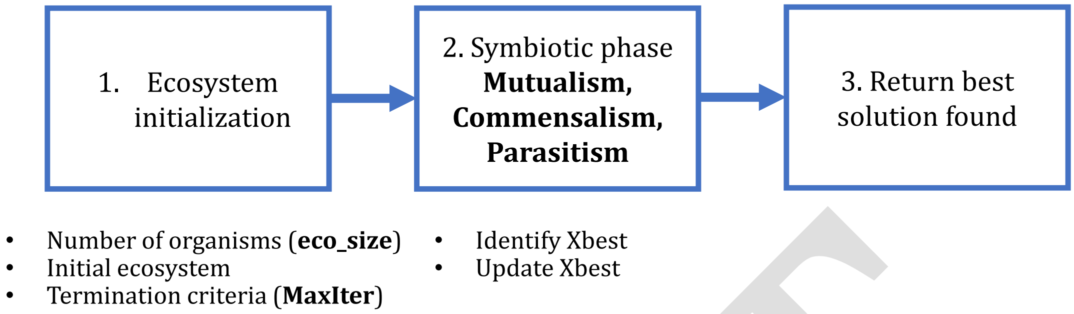

Figure 2. Basic steps of SOS algorithm

In all population-based metaheuristic algorithms specific operations are performed with the objective to generate new organisms in each population. For example, a genetic algorithm has two operations, named crossover and mutation. Harmony search algorithm proposes three rules to improvise a new harmony, named memory considering, pitch adjusting, and random choosing. Artificial bee colony algorithm also proposes three phases, named employed bee, onlooker bee, and scout bee phases. In SOS, these are mutualism phase, commensalism phase, and parasitism phase.

3. A DISCRETE SYMBIOTIC ORGANISMS SEARCH BASED 2-OPT ALGORITHM

The main steps of the DSOS algorithm include mutualism phase, commensalism phase, and parasitism phase. The initial ecosystem is produced randomly with the condition that all solutions need to be feasible.

3.1 Mutualism phase

In mutualism phase, X*i* is an organism matched to the *i*th member of the ecosystem. Another organism X*j* is then selected randomly from the ecosystem to interact with X*i*. Both organisms engage in a mutualistic relationship with the goal of increasing mutual survival advantage in the ecosystem. New candidate solutions for X*i* and X*j* are calculated based on the mutualistic symbiosis between organisms X*i* and X*j*, which is modeled in Eqs. (1) and (2).

$$X_{inew} = X_i + rand(0,1) * (X_{best} - Mutual\_Vector * BF_1) \qquad (1)$$

$$X_{jnew} = X_j + rand(0,1) * (X_{best} - Mutual\_Vector * BF_2) \qquad (2)$$

where $Mutual\_Vector = \frac{X_i+X_j}{2}$, $rand(0,1)$ generates a value between 0 and 1, and BF_1 and BF_2 are determined randomly using the expression $BF_1 = BF_2 = 1 + round[rand(0,1)]$. The new candidate solutions X_{inew} and X_{jnew} are accepted only if they provide better fitness values than X_i and X_j, respectively. If new and improved solutions are found, the 2-OPT algorithm is applied on that solution before it is inserted back into ecosystem.

3.2 Commensalism phase

In commensalism phase, once again, an organism X*j* is selected randomly from the ecosystem to interact with X*i*. In this interaction, an organism X*i* aims to benefit. The new candidate solution of X*i* is calculated based on the commensal symbiosis between organisms X*i* and X*j*, which is modeled in Eq. (3).

$$X_{inew} = X_i + rand(-1,1) * (X_{best} - X_j) \quad (3)$$

where $(X_{best} - X_j)$ represents a benefit provided by X_j to help X_i increase a likelihood of survival. The new candidate solution X_{inew} is accepted only if it provides better fitness values than X_i. If the new and improved solution is found, the 2-OPT algorithm is applied on that solution before it is inserted back into ecosystem.

3.3 Parasitism phase

In parasitism phase, an organism X*i* is mutated and the parasite organism, labelled as X*pv*, is created. The organism X*j* is selected randomly from the ecosystem for comparison. In this interaction, if the fitness value of the X*pv* is better than the fitness value of the X*j*, then the X*j* will be replaced with the X*pv*. In addition, the 2-OPT algorithm is applied on the X*pv*. In opposite, an organism X*j* will develop immunity from the parasite organism X*pv* and parasite organism will be removed.

The operators, named insertion, inversion, and swap are used to generate the parasite organism. These operators are proposed by Wang, Lin, Zhong, and Zhang (2015). Only one of the three operators is used for computation of the parasite organism based on a random value.

3.4 A 2-OPT algorithm for TSP

The 2-OPT algorithm for TSP was proposed by Lin (1965). In this algorithm, a path is constructed as follows:

Step 1. Find an initial tour randomly or by applying some other algorithm.

Step 2. Try to improve the tour using the two-branch exchange method.

Step 3. Continue Step 2 for all combinations and return the improved tour or the tour that is already 2-optimal.

4. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, we perform experimental results to analyze the performance of the DSOS+2-OPT algorithm for TSP. The parameters used for the proposed DSOS+2-OPT are selected to be to be consistent with the parameters of DSOS (Ezugwu and Adewumi, 2017) in order to make an appropriate comparison. Therefore, MaxIter is 1000, eco_size is 50, and each experiment was executed 10 times independently.

The algorithm is implemented in Matlab and the experiments are run on a desktop computer with an Intel Core i5-2400, 3.1 GHz processor. The authors conducted the experiments on 14 symmetric benchmark instances from TSPLIB (Reinelt, 2022). The obtained experimental results from the proposed DSOS+2-OPT algorithm are compared with the results from the first proposed version of the DSOS (Ezugwu and Adewumi, 2017).

Table 1. Comparison results between the proposed DSOS+2-OPT algorithm and the DSOS algorithm

	DSOS (Ezugwu and Adewumi, 2017)				**DSOS+2-OPT**			
Instance Opt. val.	**Best**	**Mean**	**PDav**	**Time (s)**	**Best**	**Mean**	**PDav**	**Time (s)**
Eil51 426	**426**	427.90	0.45	62.5	428	431.3	1.24	16.28
St70 675	**675**	679.20	0.62	82.58	676	681.7	0.99	16.98
Eil76 538	542	547.40	1.75	93.86	548	554.80	3.12	17.22
KroD100 21294	**21294**	21493.10	0.94	139.70	21464	21686.80	1.84	18.25
Eil101 629	640	650.60	3.43	171.75	649	655.10	4.15	18.16
Pr124 59030	**59030**	59429.10	0.68	235.57	59076	59497.20	0.79	19.20
Pr136 96772	97437	97673.20	0.93	448.08	97755	99290.90	2.60	19.54
Pr152 73682	74013	74785.70	1.50	516.68	74020	74575.70	1.21	20.45
Pr264 49135	50424	52798.90	7.46	622.90	50855	51778.90	5.38	28.25
Pr299 48191	49162	50335.20	4.45	705.27	50109	51132.90	6.10	31.65
Lin318 42029	42201	42972.42	2.24	925.47	43955	44213	5.20	34.06
Rat575 6773	7030	7117.32	5.08	973.86	7312	7382.60	9.00	88.52
Rat783 8806	9045	9102.67	3.37	1043.61	9556	9685.40	9.99	212.89
Pr1002 259045	271381	278381.51	7.46	1843.34	278425	279903.30	8.05	518.06
Average			2.88	561.80			4.49	75.68

In Table 1, the proposed DSOS+2-OPT algorithm is performing slightly worse, on average basis, than the DSOS (Ezugwu and Adewumi, 2017) for 12 out of 14 tested instances. However, if we compare CPU time, the proposed DSOS+2-OPT algorithm is performing significantly better on average basis, than the DSOS (Ezugwu and Adewumi, 2017) for all tested instances. In terms of the quality of the best solution found the DSOS (Ezugwu and Adewumi, 2017) outperforms the proposed DSOS+2-OPT for all tested instances.

Based on the relatively poor quality of the average solution found and high computational time of both compared algorithms we can conclude that both algorithms have relatively poor local search mechanisms. The DSOS (Ezugwu and Adewumi, 2017) algorithm fills that gap with the extensive search which reflects the long execution time. The proposed DSOS+2-OPT can be improved even further with some other local search approaches.

5. FINAL REMARKS AND CONCLUSION

In this study, we have presented the basic version of the DSOS algorithm which is additionally improved with the 2-OPT algorithm. The proposed DSOS+2-OPT algorithm is easy to implement, with acceptable execution efficiency, that is, satisfactory CPU times. The algorithm has good global search, but relatively poor local search.

The future work could focus on extending the research on different strategies of how to prevent premature convergence of the proposed DSOS+2-OPT algorithm. The use of some other tour construction and tour improvement algorithms can be investigated. Also, the hybridization with some other metaheuristic algorithms should be explored.

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PART III

REVERSE LOGISTICS AND GREEN LOGISTICS

DEVELOPMENT OF A MODEL FOR ESTIMATING COMMERCIAL VEHICLES' FUEL CONSUMPTION AND EXHAUST EMISSIONS

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Abstract: *In this paper, an estimation model of fuel consumption and exhaust emissions of commercial vehicles in different operating conditions is developed. Depending on vehicle's average speed, road slope and vehicle's load/capacity utilization, the model determines the fuel consumption and emissions of harmful gases for the observed vehicle type and category. In order to validate the model, recordings on actual commercial vehicles were made in real operating conditions on two urban public transport bus lines in Belgrade. Obtained fuel consumption in real operating conditions and estimated fuel consumption by the developed model were compared. Deviations of the estimation model from the real consumption values are on average about 5%. After a successful fuel consumption validation, the emissions of the most common harmful gases by the model are estimated.*

Keywords: *estimation model, validation, fuel consumption, GHG emissions*

1. INTRODUCTION

If a transport operator wishes to become sustainable, it has to operate efficiently by reducing transport costs, maintenance costs and/or by increasing the fleet energy efficiency (Kamakaté and Schipper, 2009; Ruzzenenti and Basosi, 2009; Vujanović et. al., 2018). Since fuel consumption represents a major operating cost for transport companies (Gohari et. al., 2018; Kot, 2015; Kovács, 2017) and they mostly operate heterogeneous vehicle fleets (Hoff et. al., 2010), adequate vehicle selection for existing transport volumes represents one of fleet management's key activities. By selecting a more fuel-efficient vehicle, lower fuel costs and greater vehicle autonomy will be achieved (Lin et. al., 2009). Additionally, one of the parameters that represents sustainable fleet management is the reduction of harmful gas emissions (Ansaripoor et. al., 2014). Reduction of fleet's harmful gas emissions and increase of its energy efficiency can be achieved through the selection of vehicles of appropriate type and category (Liimatainen and Pöllänen, 2010), as well as through increasing their load/capacity utilization index (Vujanović et. al., 2010).

Based on all previously mentioned, this paper presents a model allowing fuel consumption and harmful gases emissions estimation on the observed transport routes depending on following vehicle and road characteristics:

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- commercial vehicle category,
- commercial vehicle emission standard,
- speed profile,
- road slope and
- load/capacity utilization index.

The aim of this paper is to develop an estimation model which will make it possible to quickly and easily determine the fuel consumption and GHG emissions for different commercial vehicles in dominant actual operating conditions. The model was developed in Matlab 2018, and its validation was performed on data obtained by recordings in real-world operating conditions of standard buses deployed on lines 53 and 83 of urban public transport in Belgrade, Serbia.

The paper is structured as follows. In the second section, one of the most commonly used models for determining fuel consumption and exhaust emissions is described, after which the third chapter provides a step-by-step overview of the developed model for fuel consumption and exhaust emissions estimation. Afterwards, in the fourth chapter, the model validation was performed on buses operating on two urban public transport lines in both directions, at different measured speeds, road slopes and capacity utilization indices. Finally, in the fifth chapter, some concluding remarks, as well as main directions for future research are suggested.

2. MODELS FOR FUEL CONSUMPTION AND EXHAUST EMISSIONS DETERMINATION

By conducting a literature review the authors found that EMEP/EEA air pollutant emission inventory guidebook represents the referent source for determining fuel consumption and emission factors for various exhaust gases (European Environment Agency, 2019). Its “road transport appendix 4 emission factors” (Ntziachristos and Samaras, 2021) is the database that shows the average fuel consumption and exhaust emissions expressed in grams per kilometer (g/km), which allows determining the exhaust emissions before reaching the regular engine operating temperature (i.e., cold emissions) as well as after (i.e., hot emissions). The exhaust emissions are determined for different: speed profiles, gear shifting strategies, vehicle capacity utilization indices, road slopes, vehicle characteristics, etc. Exhaust emissions data contained in the model were obtained on the basis of a large number of measurements performed both in laboratory conditions and in real operating conditions using a Portable Emission Measurement System (PEMS). (ERMES - European Research on Mobile Emission Sources, 2020; Hausberger et al., 2019)

The reference database of road transport related emission factors contains a very large set of data on fuel consumption and exhaust emissions for each vehicle type and category. These values were obtained based on vehicle measurements at different segmented load/capacity utilizations (0%, 50% and 100%), road slopes (-6%, -4%, -2%, 0 %, 2%, 4% and 6%), as well as at different speeds. The main disadvantage of this database is that it does not provide values of fuel consumption and exhaust emissions for other load/capacity utilization indices and road slopes that are in-between intervals of predefined and previously shown values (e.g., capacity utilization of 37% and road slope of 2.42%).

In that sense, the following chapter gives a brief explanation of the model developed in Matlab, which estimates fuel consumption and emissions for different vehicle types and categories, for any value of vehicle speed, road slope and vehicle capacity utilization index.

3. ESTIMATION MODEL DEVELOPMENT

Within this chapter, the steps of the model for fuel consumption and exhaust emissions estimation for different vehicle types and categories are presented. The proposed model is supplied with data from the reference database of fuel consumption and exhaust emissions for different vehicle types and categories.

Within the first step, all necessary technical characteristics of the vehicle are defined, such as type (e.g. heavy duty vehicle or bus) and vehicle category (e.g. heavy rigid vehicle 7.5 - 12 t, heavy articulated vehicle 20 - 28 t, urban bus articulated >18 t, urban bus standard 15-18 t, urban bus midi ≤15 t, etc.), as well as vehicle Euro standard (Conventional, Euro I - Euro VI).

In the second step the following operating conditions are defined: average speed (km/h), vehicle load/capacity utilization (%), longitudinal road slope (%) and trip distance (m).

After the vehicle technical characteristics and operating conditions are defined, in the third step, presented model estimates output parameters: fuel consumption (FC) and emissions of carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbon (HC), and particulate matter (PM). The model compares imported values with existing discretized data from reference database and estimates output values based on bilinear interpolation (Press et. al., 1992). The model is designed to take any value of vehicle speed, load/capacity utilization and road slope, and based on bilinear (repeated linear) interpolation of existing discretized values estimates desired output parameters. For example, if the observed speed is 15 km/h, the road slope is 2.8% and the vehicle load/capacity utilization is 75%, the model takes left and right boundary values of reference database discretized data. These four values for vehicle speed of 15 km/h, are denoted as follows (Figure 1):

1) Q_{11} - value when the road slope is 2%, the vehicle load/capacity utilization is 50%;
2) Q_{12} - value when the road slope is 2%, the vehicle load/capacity utilization is 100%;
3) Q_{21} - value when the road slope is 4%, the vehicle load/capacity utilization is 50%; and
4) Q_{22} - value when the road slope is 4%, the vehicle load/capacity utilization is 100%.

The R_1 value is found by first linear interpolation of the values Q_{11} and Q_{21} in the road slope axis direction, and R_2 from Q_{12} and Q_{22}. After obtaining the values of R_1 and R_2, repeated linear interpolation is performed to obtain the point P (Figure 1) which represents the final result of the observed parameter for road slope of 2.8% and vehicle load/capacity utilization of 75%.

As the values of fuel consumption and exhaust emissions from the reference database are presented in g/km, the total trip distance is calculated in order to determine the total fuel consumption/exhaust emissions at the observed bus line. When calculating fuel consumption, it is necessary to take into account the specific density of the observed fuel to obtain the consumption in liters. In this paper, the average density of diesel used in calculations is 830 g/l.

Presented model is validated in real-world operation conditions on public transport buses in Belgrade.

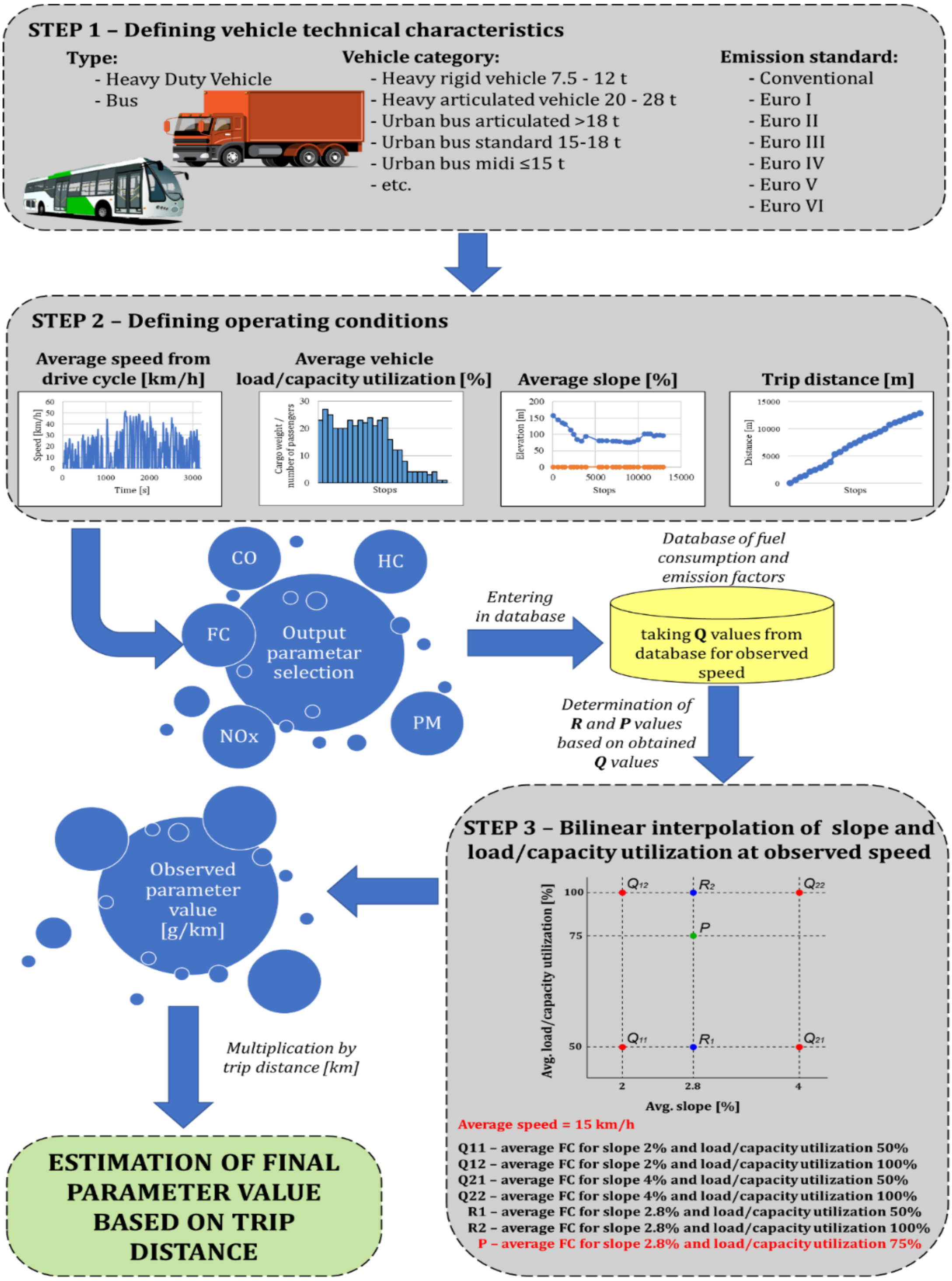

Figure 1. Schematic representation of the model

4. MODEL VALIDATION

The model validation was performed on recorded data of buses' operation on lines 53 and 83 of Belgrade public transport, in both directions. Data were recorded on a HIGER standard diesel bus, type KLQ6129GQ2 manufactured by Chariot Motors, shown on Figure 2. The observed buses meet the emission norms set by Euro VI standard. The maximum capacity of the buses is 100 seats (29 seats and 71 standing places).

Figure 2. Diesel bus Higer KLQ6129GQ2

Data recording on line 83 was performed on February 14, 2020 from 9 AM to 11.45 AM, while data recording on line 53 was performed six days later (February 20, 2020) from 9 AM to 10.45 AM. Each data recording was preceded by equipment mounting and testing. Data on actual vehicle speed and current fuel consumption were collected using PCAN-USB Pro - PEAK (Figure 3 - left), while Garmin GPSMAP 62s (Figure 3 - right) was used to collect altitude data used for average road slope determination. The percentage of bus capacity utilization was determined by systematic passenger counting.

Figure 3. The Appearance of PEAK (left) and GARMIN (right) devices

Line 83 is a moderately difficult diametrical line connecting two peripheral settlements (Crveni krst) and (Zemun) through the central city core. The length of the line in the direction from Crveni krst to Zemun (direction A) is 12,914 m, while in the opposite direction (B), the length is 13,624 m. Unlike line 83, 53 is moderately heavy radial line connecting the central city zone (Zeleni venac) with the peripheral settlement (Vidikovac). The length of this line in both directions (A and B) is about 12,925 m. The position of these bus lines, as well as the start and end terminal stations are shown in Figure 4.

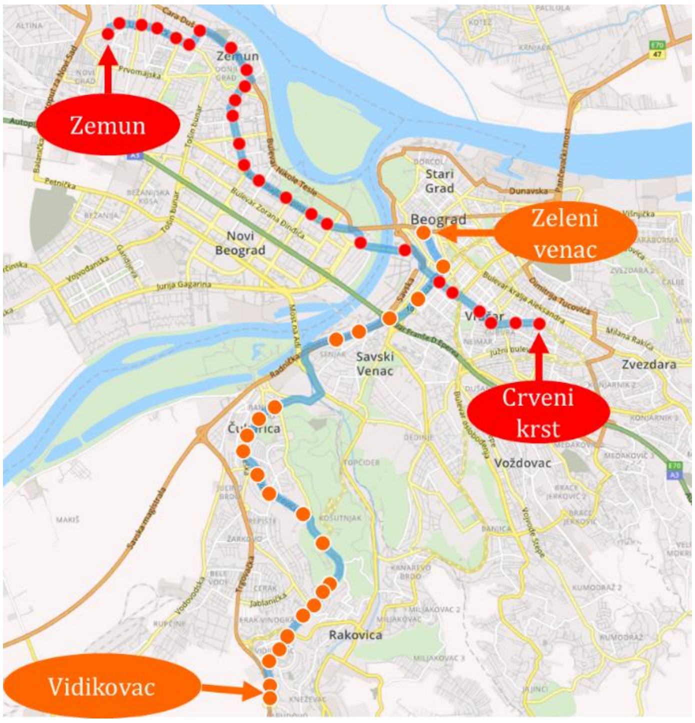

Figure 4. Position of bus lines and start and end terminal stations

The longitudinal road slope of the observed lines in the direction A is given in Figure 5.

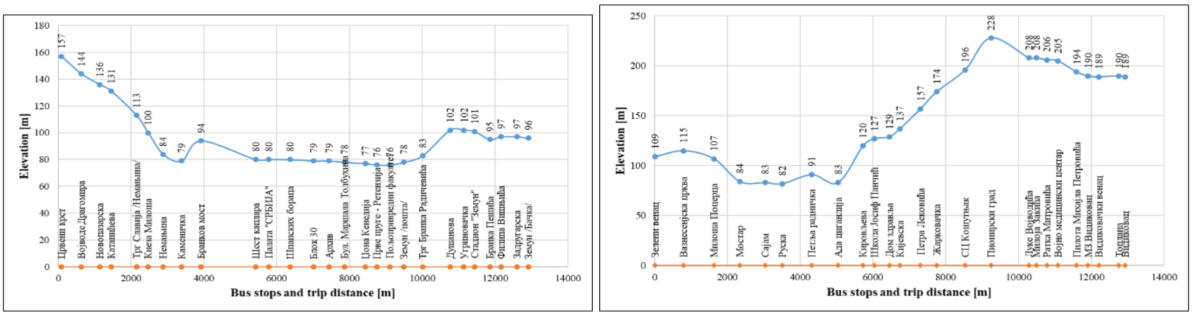

Figure 5. Recorded road slope on line 83 (left) and line 53 (right) in direction A

Urban driving conditions can be observed through speed profile recorded in real-world operating conditions for each bus line. From Figure 6 it can be seen that the speed profile is characteristic for urban driving conditions due to lower speeds (below 50 km/h), frequent speed oscillations (acceleration and deceleration) and stops.

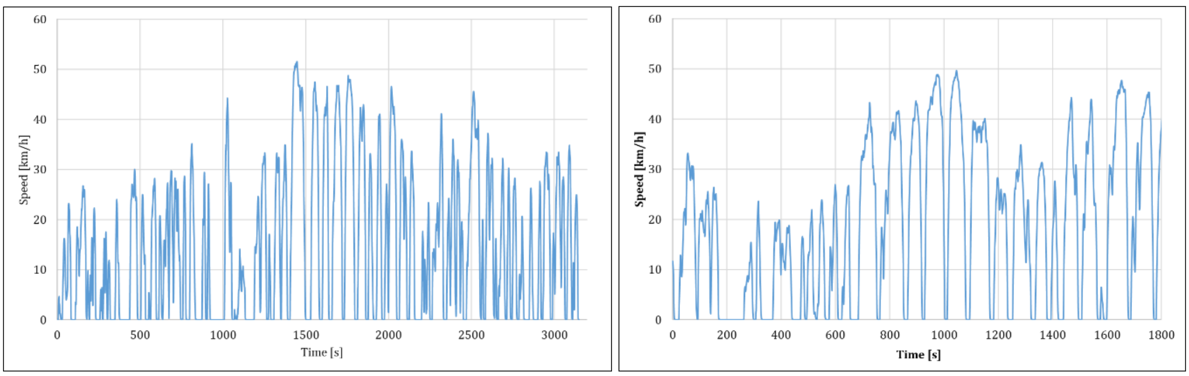

Figure 6. Recorded speed profile on line 83 (left) and line 53 (right) in direction A

After the average values of vehicle capacity utilization, trip distance and fuel consumptions are determined in real-world operating conditions, the developed model estimates output values and validate them. In Table 1 are given the values of all mentioned parameters which are used in model. Furthermore, in the same table, the recorded values of fuel consumption in real operating conditions, as well as estimated fuel consumption values are presented. It can be seen that estimated fuel consumption by the model is approximately 5% lower than fuel consumption in real operating conditions. The biggest deviation (-7.81%) is obtained on line 83 in direction A, while the smallest deviation is on line 53 in direction from Zeleni Venac to Vidikovac (-3.23%). Based on the obtained deviations, the model is validated and it can be used for determination of fuel consumption and GHG emissions.

It is important to emphasize that reference data used are not obtained for the observed vehicle and same operating conditions. Additionally, the data recording was conducted in winter conditions, with heating turned on, leading to increased fuel consumption.

Table 1. Values of the observed parameters used for model validation

Bus line	Direction [A/B]	Average speed [km/h]	Average load [%]	Average slope [%]	Line length [m]	Recorded fuel cons. [l]	Model FC [l]	Difference between FC in model and recorded FC [%]
53	A	18.59	9.2	0.62	12,925	5.56	5.38	-3.23
53	B	18.65	30.3	-0.62	12,927	4.86	4.61	-5.14
83	A	14.75	14.9	-0.47	12,914	5.53	5.08	-7.81
83	B	14.43	19.3	0.53	13,624	6.59	6.34	-3.79

After successful validation of the model in terms of fuel consumption, the emissions of GHG such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), and particulate matter (PM) are determined. The emitted quantities of these gases on the observed lines are presented in Table 2.

Table 2. The emitted values of CO, NOx, HC and PM on line 53 and 83 in both directions

Bus line	Direction [A/B]	CO [g]	NOx [g]	HC [g]	PM [g]	Bus line	Direction [A/B]	CO [g]	NOx [g]	HC [g]	PM [g]
53	A	20.77	11.75	0.51	0.08	83	A	23.04	20.79	0.55	0.07
	B	18.79	15.02	0.46	0.07		B	26.78	17.74	0.63	0.09

5. CONCLUSION

This paper presents a developed model for estimating fuel consumption and exhaust emissions in road transport. The model is based on the EMEP/EEA air pollutant emission reference database on fuel consumption and emission factors for different types and categories of commercial vehicles' speeds, load/capacity utilizations and road slopes. The contribution of this paper is reflected in the developed model for bilinear interpolation to estimate more precisely fuel consumption and exhaust emissions than those given in the observed database. Additionally, the contribution of the paper is the successful validation of the model on urban bus lines in Belgrade. The average deviation of the obtained fuel consumption in the model and the actual fuel consumption in real operating conditions is about 5%.

The modeled fuel consumptions and exhaust emissions in real operating conditions are important to logistics and transport operators in view of their carbon footprint, economic and environmental sustainability. Further benefits can be achieved by model application in selecting the most efficient vehicle category on actual transport routes. The model can also support decision making in heavy duty vehicle procurement by estimating the fuel consumption of new vehicle types and categories for existing transport demands and operating conditions.

Directions of future research is in the application of the model on other vehicle categories. Also, the model can be used for commercial vehicle fleet carbon footprint estimation in different areas of operation.

ACKNOWLEDGMENT

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E-WASTE LOGISTICS NETWORK DESIGN

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Abstract: *E-waste represents one of the fastest-growing waste streams due to rapid scientific and technological development which contains both valuable and dangerous substances. So, this waste stream requires an adequate logistics network for collection, transport, and treatment. This paper presents an approach for e-waste logistics network design which is tested on a real-scale example.*

Keywords: *e-waste, logistics network, facility location.*

1. INTRODUCTION

Electrical and electronic devices such as mobile phones, laptops, air-conditioners, etc. have become an essential part of modern everyday life. At the end of use, end-users discard electrical and electronic devices, in that way, generating an e-waste stream. In 2019, 53.6 million metric tons of e-waste were generated globally (Forti et al., 2020). The problem with e-waste, besides the generated quantities, is in its composition. Namely, e-waste contains toxic or hazardous substances, such as mercury, cadmium, brominated flame retardants (BFR), etc. On the other hand, e-waste contains precious and other metals such as iron, copper, gold, silver, etc. So, e-waste represents a valuable resource for secondary materials, if those materials are properly extracted (Figure 1).

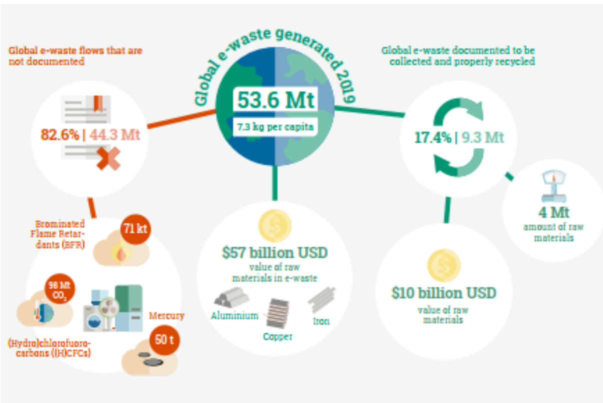

Figure 1. Global e-waste in 2019 (Forti et al., 2020)

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Another characteristic of e-waste is its reusability, that is electronic and electrical devices can be reused and sold on the secondary markets. Legislation like WEEE Directive in European Union (2002/96/EC) forces original equipment manufacturers (OEM) to take over their products, once they are discarded by users, regardless of the reason. On the other hand, the reuse of returned products, components, and reusable materials is very cost-effective for OEMs, especially with products that have a longer lifespan.

An adequate collection, transport, and treatment of e-waste creates additional flow in traditional logistics networks, and that is reverse flow of goods from end-user to OEMs (Figure 2). Logistics networks for the treatment of e-waste have additional facilities compared to traditional logistics networks, new activities, new involved parties, etc.

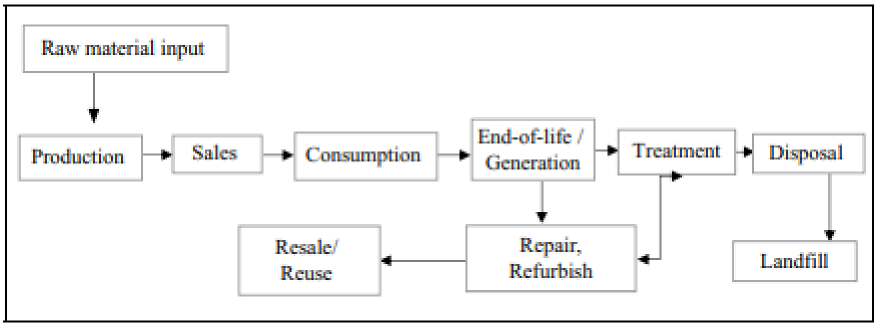

Figure 1. Life cycle of an e-product (Bhagat-Ganguly, 2022)

Many authors addressed the problem of logistics network design for e-waste. Safdar et al. (2020) proposed a multi-objective model to develop the economic, social, and environmental strategies for managing reverse logistic activities of collection, evaluation, reprocessing, and transportation of the returned electrical products. The authors used a neutrosophic optimization approach for the optimization of multi-objective networks. Kilic et al. (2015) proposed a mixed-integer linear programming model for reverse logistics network design for electronic waste in Turkey. The optimum locations of storage and recycling facilities are obtained for each of the defined scenarios. John et al. (2018) proposed an integer linear programming model which determines the optimal number and location of different facilities on the network. Mobile phones and digital cameras are considered for validation of the model. Alshamsi and Diabat (2015) proposed a mixed-integer linear program to address the complex network configuration of a reverse logistics system. The proposed model determines the optimal selection of sites, the capacities of inspection centers, and remanufacturing facilities. In this paper, we used the modified mathematical formulation for integrated logistics network design for e-waste, published in Lee and Dong (2008), and tested on a real-scale numerical example.

The paper is organized as follows. In Section 2, a description of the problem, and a mathematical formulation for logistics network design is described as well as a numerical example. Concluding remarks are given in Section 3.

2. PROBLEM DESCRIPTION

Computer equipment represents part of electric and electronic equipment that primarily does not have to be bought, that is companies can lease computer equipment from distributors or OEMs. By leasing computer equipment, companies have different benefits such as keeping the equipment up to date, and in this way, they are provided with newer equipment. Also, companies that lease computer equipment provide various services relating to repairs, proper permanent removal of data, etc. Companies that provide computer equipment lease services, in addition to the service of delivery of new products, also perform services of collecting products at the end of the lease, which results in complex logistics networks and activities. Namely, there is a need for additional facilities on the network, like collection centers for returned products or warehouses for new products. Forward and reverse flows of products can be observed separately or an integrated logistics network can be established in which forward and reverse flows are considered simultaneously.

In this paper, we used the modified mathematical model for integrated logistics network design published in Lee and Dong (2008) and tested it on a real-scale example. A company that leases computer equipment (in this paper this company will be noted as OEM) delivers it to customers (end-users). Parts or whole products of computer equipment are returned to OEM for treatment or safe disposal. In this integrated logistics network, in which forward and reverse flows of products are considered, a hybrid processing facility (HPF) is located. That is, HPF is a facility in which flows of new and returned products ones take place, and in that way OEM achieves cost savings. The aim of designing an integrated network is to choose locations of OEMs and HPFs, as well as determine the quantities of products to be shipped and return through the network in order to minimize total costs. The following notation was used in order to formulate a mathematical model:

M – a big number

CD – set of potential locations for OEMs

RD – set of potential locations for HPFs

D = CD U RD – set of all potential facility locations

C – set of all customers

E = C U RD – set of customers and potential locations for HPFs

N = D U C – set of all nodes on the network

S_k^F – quantity of the supply of new products at node k, $\forall k \in D$

D_n^F – quantity of the demand for new products at node n, $\forall n \in C$

D_k^R – quantity of the demand of returned products at node k, $\forall k \in D$

S_n^R – quantity of the supply of returned products at node n, $\forall n \in C$

C_{ij}^F – transport costs per unit of new products shipped along arc $a(i, j)$, $\forall i, j \in N$

C_{ji}^R – transport costs per unit of returned products shipped along arc $a(j, i)$, $\forall j, i \in N$

F_l – fixed costs of establishing HPF$_l$, $\forall l \in RD$

F_t – fixed costs of establishing OEM$_t$, $\forall t \in CD$

X_{ij} – quantity of new products transported from i to j, $\forall i, j \in N$

Y_{ji} - quantity of new products transported from j to i, $\forall i, j \in N$

Z_k – 1, if the facility is located, 0 otherwise, $\forall\ k \in D$

U_l – capacity of HPF$_l$, $\forall l \in RD$

q – number of HFPs to be located

t – number of OEMs to be located

The mathematical formulation of the problem is:

$$\text{Min} \sum_{l\in RD} F_l\, z_l + \sum_{p\in CD} F_p\, z_p + \sum_{i\in N}\sum_{j\in N} C_{ij}^F\, x_{ij} + \sum_{j\in N}\sum_{i\in N} C_{ji}^R\, y_{ji} \quad (1)$$

s.t.

$$\sum_{m\epsilon E} x_{km} - \sum_{i\epsilon N} x_{ik} = S_k^F z_k, \forall k\epsilon D \quad (2)$$

$$\sum_{i\epsilon N} x_{in} - \sum_{m\epsilon E} x_{nm} = D_n^F, \forall n\epsilon C \quad (3)$$

$$\sum_{i\epsilon N} y_{ni} - \sum_{m\epsilon E} y_{mn} = S_n^R, \forall n\epsilon C \quad (4)$$

$$\sum_{m\epsilon E} y_{mk} - \sum_{i\epsilon N} y_{ki} = D_k^R z_k, \forall k\epsilon D \quad (5)$$

$$\sum_{m\epsilon E} x_{km} \leq M_{zk}, \forall k\epsilon D \quad (6)$$

$$\sum_{m\epsilon E} y_{mk} \leq M_{zk}, \forall k\epsilon D \quad (7)$$

$$\sum_{n\epsilon C} y_{nl} \leq U_l, \forall l\epsilon RD \quad (8)$$

$$\sum_{p\epsilon CD} Z_p = t \quad (9)$$

$$\sum_{l\epsilon RD} Z_l = q \quad (10)$$

$$Z_k=\{0,1\}, \forall k\epsilon D \quad (11)$$

$$x_{ij} \geq 0, y_{ji} \geq 0, \forall i, j\epsilon N \quad (12)$$

The objective function (1) minimizes the total costs of establishing an integrated logistics network: the costs of establishing HPFs, the costs of establishing OEMs, the transportation costs of shipping new products from OEM locations to customers directly or via HPFs, as well as transportation costs of collecting returned products from customers to OEM directly or via HPFs. Constraints sets (2) - (5) are flow conservation constraints. Constraints (6) and (7) enable the flow of new and returned products being transferred through HPFs only if the locations for HPFs are selected by the model. Constraints (8) are the capacity constraints for HPFs. Constraints (9) and (10) define the numbers of OEMs and HPFs to be established. Constraints (11) and (12) define the nature of the variables.

2.1 Numerical example

The described model was tested on a real-scale example for Vojvodina, the northern part of the Republic of Serbia. Vojvodina consists of 45 municipalities divided into 7 districts. In this example, we assumed that there are 4 potential locations for OEMs, 12 potential locations for HPFs, and the rest 29 municipalities are customers (end-users). Those locations for OEMs, HPFs, and customers are presented in Figure 3.

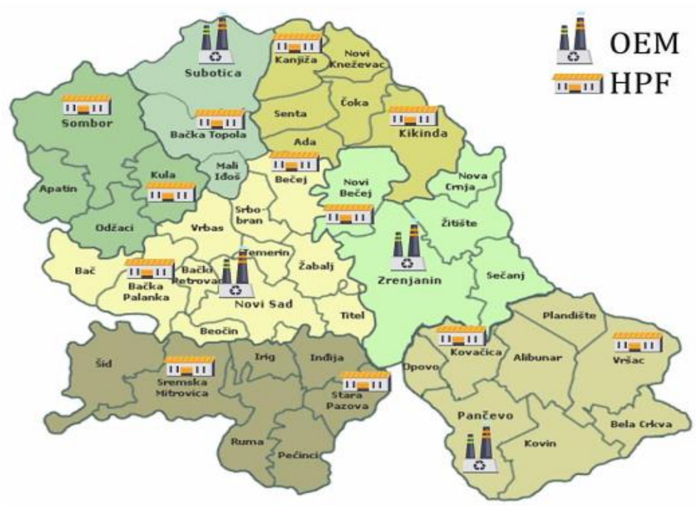

Figure 3. Potential locations for OEMs and HPFs

Input parameters for modeling are presented in tables 1 and 2. Capacities for all potential locations are sufficient. Quantities of supply and demand for new and returned products are expressed in the number of IT equipment units. This number is obtained on the basis of the number of inhabitants of each municipality and data on the number of IT equipment units placed on the market in 2020. Unit transportation costs for delivery of new products on the route OEM-end-user are set to 0.01€, OEM-HPF 0.0025€, and between HPF and end-user is set to 0.005€. Unit transportation costs for collection of returned products on the route OEM-end-user are set to 0.016€, OEM-HPF 0.004€, and between HPF and end-user is set to 0.008€. Fixed costs of opening HPFs are set to 100€, while fixed costs of opening OEMs are set to 500 €. All input parameters are normalized to a daily level.

Table 1. Input parameters for OEMs and HPFs locations

Potential locations for OEMs and HPFs	S_k^F	D_k^R
Subotica (OEM1)	451	369
Novi Sad(OEM2)	1206	987
Zrenjanin(OEM3)	382	312
Pančevo(OEM4)	396	324
Bačka Topola(HPF1)	101	83
Sombor (HPF2)	258	211
Kula(HPF3)	129	106
Bačka palanka(HPF4)	171	140
Bečej(HP5)	116	95
Kikinda(HPF6)	178	146
Kanjiža(HPF7)	78	64
Vršac(HPF8)	162	132
Kovačica(HP9)	79	64
Sremska Mitrovica(HPF10)	248	203
Stara Pazova(HPF11)	215	176
Novi Bečej(HPF12)	74	61

Table 2. Input parameters for end-users

End-user	D_n^F	S_n^R	End-user	D_n^F	S_n^R
Mali Iđoš	37	31	Ada	52	43
Apatin	87	71	Čoka	34	28
Odžaci	89	73	Žitište	49	40
Bač	43	36	Nova Crnja	31	25
Bački Petrovac	42	35	Sečanj	39	32
Beočin	50	41	Alibunar	61	50
Vrbas	129	106	Bela Crkva	53	43
Žabalj	83	68	Kovin	103	84
Srbobran	51	42	Opovo	32	26
Temerin	92	76	Plandište	34	28
Titel	50	41	Inđija	151	124
Sremski Karlovci	28	23	Irig	33	27
Novi Kneževac	34	28	Pećinci	64	52
Senta	72	59	Ruma	170	139
			Šid	102	84

The model was developed by Python programming language and solved by open-source software LP Solve IDE. We tested the proposed model for different values of parameters t and q. Parameter t is set to 1, 2 and 3, while parameter q takes values from range [1, 12]. The obtained results are presented in tables 3, 4, and 5.

Table 3. Numerical results for t = 1 and q = [1, 12]

Parameter *t* value	**Parameter *q* value**	**Objective function value**	**Opened OEM**	**Opened HPFs**									
1	1	2572.97	OEM2	HPF5									
	2	2285.05	OEM2	HPF11	HPF5								
	3	2174.7	OEM2	HPF3	HPF11	HPF5							
	4	2106.28	OEM2	HP3	HPF11	HPF5							
	5	2065.89	OEM3	HPF2	HPF5	HPF8	HPF10	HPF11					
	6	2078.01	OEM3	HPF2	HPF8	HPF5	HPF8	HPF14	HPF11				
	7	2098.9	OEM3	HPF2	HPF8	HPF5	HPF8	HPF14	HPF11	HPF9			
	8	2136.31	OEM3	HPF2	HPF3	HPF8	HPF5	HPF8	HPF10	HPF11	HPF9		
	9	2182.38	OEM3	HPF2	HPF3	HPF8	HPF5	HPF8	HPF10	HPF11	HPF9	HPF7	
	10	2283.51	OEM3	HPF2	HPF3	HPF8	HPF5	HPF8	HPF10	HPF11	HPF9	HPF7	HPF12

Table 4. Numerical results for t = 2 and q = [1, 12]

Parameter *t* value	**Parameter *q* value**	**Objective function value**	**Opened OEMs**	**Opened HPFs**								
2	1	2836.2	OEM3 OEM4	HPF3								
	2	2686.29	OEM3 OEM4	HPF5	HPF11							
	3	2579.23	OEM3 OEM4	HPF5	HPF11	HPF2						
	4	2560.03	OEM3 OEM4	HPF5	HPF11	HPF2	HPF1					

Parameter *t* value	**Parameter *q* value**	**Objective function value**	**Opened OEMs**	**Opened HPFs**								
	5	2514.5	OEM3 OEM4	HPF5	HPF11	HPF2	HPF5	HPF10				
	6	2558.45	OEM3 OEM4	HPF5	HPF11	HPF2	HPF4	HPF10	HPF9			
	7	2637.05	OEM3 OEM4	HPF5	HPF2	HPF5	HPF7	HPF9	HPF10	HPF11		
	8	2735.88	OEM3 OEM4	HPF5	HPF7	HPF9	HPF10	HPF11	HPF3	HPF4	HPF12	
	9	3166.72	OEM3 OEM4	HPF5	HPF7	HPF9	HPF3	HPF4	HPF12	HPF1	HPF6	HPF8

Table 5. Numerical results for t = 3 and q = [1, 12]

Parameter *t* value	**Parameter *q* value**	**Objective function value**	**Opened OEMs**	**Opened HPFs**					
3	1	3551.84	OEM1 OEM3 OEM4	HPF3					
	2	31522.9	OEM1 OEM3 OEM4	HPF1	HPF11				
	3	3103.15	OEM1 OEM3 OEM4	HPF1	HPF11	HPF10			
	4	3076.167	OEM1 OEM3 OEM4	HPF3	HPF11	HPF7	HPF8		
	5	3132.35	OEM1 OEM3 OEM4	HPF3	HPF11	HPF7	HPF8	HPF12	
	6	3318.52	OEM1 OEM3 OEM4	HPF1	HPF5	HPF9	HPF7	HPF11	HPF12

In case when only one OEM is located, a maximum of 10 HPFs can be opened. The model hasn't feasible solutions for locating 11 and 12 HPFs, due to input data. Minimal costs of 2065.59€ are achieved for locating 5 HPFs (HPF2, HPF8, HPF11, HPF10, HPF5) (Table 3). In case when 2 OEMs are located, a maximum of 9 HPFs can be opened. The model hasn't feasible solutions for locating 10, 11, and 12 HPFs, due to input data. Minimal costs of 2514.5€ are achieved for locating 5 HPFs (HPF2, HPF8, HPF11, HPF10, HPF5) (Table 4). In case when 3 OEMs are located, a maximum of 6 HPFs can be opened. The model hasn't feasible solutions when number of HPFs is larger than 7, due to input data. Minimal costs of 3076.17€ are achieved for locating 4 HPFs (HPF7, HPF11, HPF12, HPF15) (Table 5).

Allocation of direct and reverse flows of products are presented in tables 6, 7 and 8, for different values of parameters t and q and minimal values of objective functions. In case when one location for OEM is determined (Table 6), allocation of direct and reverse flows of products is done through five HPFs.

Table 6. Allocation of product flows for t = 1 and q = [1, 12]

Direct flows/Reverse flows	Zrenjanin (OEM3)	Sombor (HPF2)	Vršac (HPF8)	Stara Pazova (HPF11)	Bečej (HPF5)	Sremska Mitrovica (HPF10)
Mali Iđoš					37/31	
Apatin		87/71				
Odžaci		89/73				
Bač		43/36				
Bački Petrovac		39/31			3/2	
Beočin					50/41	
Vrbas					129/106	
Žabalj	83/68					

Direct flows/Reverse flows	Zrenjanin (OEM3)	Sombor (HPF2)	Vršac (HPF8)	Stara Pazova (HPF11)	Bečej (HPF5)	Sremska Mitrovica (HPF10)
Srbobran					51/42	
Temerin					92/76	
Titel	50/41					
Sremski Karlovci				23/23		
Novi Kneževac					34/28	
Senta					72/59	
Ada					52/43	
Čoka					34/28	
Žitište	49/40					
Nova Crnja					31/25	
Sečanj	39/32					
Alibunar			61/50			
Bela Crkva			53/43			
Kovin			103/84			
Opovo	32/26					
Plandište			34/28			
Inđija				151/124		
Irig				33/27		
Pećinci				64/52		
Ruma				24/20		146/119
Šid						102/84

Table 7. Allocation of product flows for t = 2 and q = [1, 12]

Direct flows/ Reverse flows	Zrenjanin (OEM3)	Pančevo (OEM4)	Sombor (HPF2)	Bečej (HPF5)	Stara Pazova (HPF11)	Vršac (HPF8)	Sremska Mitrovica (HPF10)
Mali Iđoš			37/31				
Apatin			87/71				
Odžaci			89/73				
Bač			43/36				
Bački Petrovac							42/35
Beočin					50/41		
Vrbas				127/106			
Žabalj	83/68						
Srbobran				51/42			
Temerin				92/76			
Titel					50/41		
Sremski Karlovci					28/23		
Novi Kneževac				34/28			
Senta				72/59			
Ada				52/43			
Čoka				34/28			
Žitište	49/40						
Nova Crnja				31/25			
Sečanj						39/32	
Alibunar						53/50	
Bela Crkva						61/43	
Kovin		103/84					
Opovo		32/26					
Plandište						34/28	
Inđija					151/124		
Irig					33/27		
Pećinci					64/52		
Ruma					66/55		104/84
Šid							102/84

In case when two locations for OEMs are opened, allocation of direct and reverse flows of products is done through five HPFs, where flow allocation for HPF8, HPF11 HPF10 is done through OEM4, while flow allocation for HPF2 and HPF5 is done through OEM3 (Table 7). The number of HPFs is the same as in the scenario for opening only one location for OEM, but since more objects are opened in this scenario total costs are higher.

Table 8. Allocation of product flows for t = 3 and q = [1, 12]

Direct flows/ Reverse flows	Zrenjanin (OEM3)	Pančevo (OEM4)	Kula (HPF3)	Vršac (HPF8)	Stara Pazova (HPF11)	Kanjiža (HPF7)
Mali Iđoš			37/31			
Apatin			87/71			
Odžaci			89/73			
Bač			43/36			
Bački Petrovac			42/35			
Beočin					50/41	
Vrbas			129/106			
Žabalj	83/68					
Srbobran			51/42			
Temerin	92/76					
Titel	50/41					
Sremski Karlovci					28/23	
Novi Kneževac						34/28
Senta						72/59
Ada						52/43
Čoka						34/28
Žitište	49/40					
Nova Crnja	31/25					
Sečanj	25/21			14/11		
Alibunar				61/50		
Bela Crkva				53/43		
Kovin		103/84				
Opovo		32/26				
Plandište				34/28		
Inđija					151/124	
Irig					33/27	
Pećinci					64/52	
Ruma					170/139	
Šid					102/84	

In case when three locations for OEMs are determined, allocation of direct and reverse flows of products is done through four HPFs, where flow allocation for HPF8 is done through OEM3, while flow allocation for HPF15 is done through OEM4 (Table 8). Also, since OEM1 supplies only HPF7 (349/288) and HPF3 (114/98) flows from and to OEM1 aren't presented in table 8. The total number of objects that are opened in this scenario is the same as in scenario 2, but since the opening of OEMs is more costly than HPFs, total costs are higher. It should be noted that one of the main characteristics of return flows is uncertainty in quantities of return products, while in this model those quantities are considered deterministic. In terms of total system costs, as expected, opening a larger number of objects on the network contributes to higher costs. However, the increase in costs is not so significant, compared to the number of opened objects in all scenarios of model testing.

3. CONCLUSION

This paper presents an approach for logistics network design in which forward and reverse flows of electronic products are considered. The proposed mathematical model can be applied to design an integrated logistics network with delivery and return flows of products, in which the same facility serves as a distribution center and collection center. The proposed model is tested on a real-scale example and the decision-maker is presented with different network configurations. Results of model testing showed that the model is dependent on input parameters, especially quantities of returned products and fixed costs of opening facilities. Hence, future research will focus on model upgrading to include consideration of uncertainty in determining model parameters (quantities of return products), different fixed costs per potential location, different capacities of located objects, involving different approaches for problem solving, etc.

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LOGISTICS NETWORK DESIGN FOR HEALTH-CARE WASTE

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Abstract: *Health-care waste represents, generally speaking, all the waste generated by healthcare facilities, laboratories, biomedical research facilities, etc. If health-care waste isn't properly treated and safely disposed of, it poses a serious risk for disease transmission among all involved actors in health-care waste management as well as the population in the vicinity of locations where health-care waste is inadequately disposed of. This paper presents an approach for health-care waste logistics network design. The aim of the proposed model is to determine the locations of collection and treatment centers for health-care waste, which is tested on a real-scale example for Belgrade city.*

Keywords*: health-care waste, logistics network, facility location.*

1. INTRODUCTION

Health-care waste (HCW) represents waste generated in healthcare institutions such as hospitals, dental practices, veterinary clinics, laboratories, etc., regardless of its composition, characteristics and/or origin. About 85% of the HCW produced is non-hazardous generated from the administrative, kitchen and housekeeping functions of health-care facilities, while the remaining 15% of HCW is hazardous and can pose a number of health and environmental risks (WHO, 2017). Hazardous HCW includes infectious waste, pathological waste, sharps waste, chemical waste, pharmaceutical waste, cytotoxic waste and radioactive waste. If non-hazardous waste is not segregated at the point of generation, it must be classified and treated as hazardous waste, meaning that the quantity of waste categorized as hazardous is unnecessarily much higher than it needs to be – increasing not only the environmental impacts of disposal methods, but also the financial costs of disposal and treatment (HCWHE, 2022). For example, the number of new infections of hepatitis B, hepatitis C, and HIV caused by contaminated syringes have been 21 million, 2 million, and 260,000, representing almost 32%, 40%, and 5% of all new infections, respectively (WHO, 2018). Hence, it is necessary to establish a system for proper management and treatment of HCW, in order to minimize risk for involved parties

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(health-care workers, waste handlers, etc.). The risk associated with inadequate management of HCW usually regards exposure to infections, toxic effects and injuries. Also, the response to the COVID-19 pandemic has accelerated the demand, use, and disposal of HCW, especially discarded personal protective equipment (PPE) and single-use plastics (Singh et al, 2022).

The first activity in HCW management is the segregation of HCW based on its characteristics. The segregation of HCW at the point of generation through appropriate waste containers reduces the risk associated with HCW. WHO recommended a segregation and collection scheme based on a uniform color coding system (Table 1) which provides a visual indication of the potential risk posed by the HCW in the container and makes it easier to put waste items into the correct container and maintain segregation during transport, storage, treatment and disposal (WHO, 2017).

Table 1. A uniform color coding system for HCW (WHO, 2017)

Waste categories	Markings and container color	Container type	Collection frequency
Infectious waste	Yellow with biohazard symbol (highly infectious waste should be additionally marked *HIGHLY INFECTIOUS*	Leak-proof strong plastic bag placed in a container (bags for highly infectious waste should be capable of being autoclaved)	When three-quarters filled or at least once a day
Sharp waste	Yellow, marked *SHARPS* with biohazard symbol	Puncture-proof container	When filled to the line or three-quarters filled
Pathological waste	Yellow with biohazard symbol	Leak-proof strong plastic bag placed in a container	When three-quarters filled or at least once a day
Chemical and pharmaceutical waste	Brown, labeled with appropriate hazard symbol	Plastic bag or rigid container	On-demand
Radioactive waste	Labeled with a radiation symbol	Lead box	On-demand
General waste	Black	Plastic bag inside a container or container which is disinfected after use	When three-quarter filled or at least once a day

Choice of treatment method depends on local conditions and involves consideration of available resources including technical expertise, relevant national regulations and requirements, waste characteristics and volume, technical requirements for installation, operation and maintenance of the treatment system, safety and environmental factors and cost considerations (WHO, 2017). Treatment methods for HCW are presented in Table 2.

Table 2. HCW categories and treatment methods (The Global Fund, 2020)

Waste categories	Treatment methods
Infectious waste	Infectious waste can be incinerated or can be treated using thermal, chemical, biological and/or irradiative techniques. Treated wastes can then be disposed of in a sanitary landfill. Autoclaving is the most widely practiced method of infectious waste treatment where it is available. Other thermal waste treatment options include microwaving, electrothermal disinfection, frictional heating, and dry heating.
Sharp waste	This waste stream requires the use of secure, rigid, and impenetrable storage bins (ideally color-coded, with a secure one-way needle deposition system).
Pathological waste	Wastes of this type must be either buried or incinerated. Lab cultured pathological wastes should be autoclaved in the lab before disposal. Pathological wastes are often disposed of using the same channels as dead bodies (either incinerated, or buried), and in a health care setting are often handled by the same contractor/department responsible for those. Local culture also has an impact on disposal. In some areas of the world, certain pathological waste, such as placentas must be treated in a culturally appropriate fashion (for instance, placentas being taken home by the mother for home-burial). Some pathological wastes have been bio digested using Anaerobic Digestion (AD) technology.
Chemical and pharmaceutical waste	The health care implications of chemical waste depend on its nature. Less hazardous chemical wastes may be diluted and disposed of using sewage/wastewater drains in countries where there is adequate infrastructure (if allowed by local legislation). Where possible, chemical wastes should be returned to the supplier, or passed on to a licensed contractor, or suitable government body for disposal. Hazardous chemical wastes of different compositions should be stored separately to avoid unwanted chemical reactions. As with chemical waste, the properties of pharmaceutical waste can vary significantly. Ideally, hospitals should avoid allowing pharmaceutical products to expire, by using “just in time” procurement.
Radioactive waste	The treatment and disposal of radioactive waste are generally under the jurisdiction of a nuclear regulatory agency.
General waste	Typically, MSW may be incinerated, landfilled, or sent to a materials recovery facility to have any recyclable content sorted from it.

In the HCW management system, storage areas must have enough capacity to hold the waste generated until it can be disposed of properly which depends on generated quantities as well as the frequency of collection and disposal (The Global Fund, 2020). So, a proper HCW management system should include facilities for storage, transport and treatment of HCW in a safe and sound manner.

Many authors addressed the problem of logistics network design for HCW. Budak and Ustundag (2017) proposed mixed-integer programming model in order to make location-allocation decisions for transport, collection and treatment of HCW. Proposed model was tested on real-scale example in Turkey. Torkayesh et al. (2021) proposed a planning framework for HCW by minimizing the total cost of the system (establishment cost, operational cost, transportation cost) and its environmental pollutants as well as maximizing job creation opportunities. The proposed model was tested on an illustrative example. Yu et al. (2020) proposed a multi-objective mixed-integer linear programming model for reverse logistics network design in case oan f epidemic outbreak. The main goal of the proposed model was to locate temporary warehouses for HCW storage as well as define transportation routes for effective HCW management. The proposed model was tested for a pandemic outbreak of COVID-19 in Wuhan, China. Shi et al. (2009) developed a mixed-integer linear programming model to minimize the total logistics costs of the reverse network for HCW using the genetic algorithm. The subject of this paper is HCW and its disposal, while the aim of this paper is to design a logistics network for the collection, transport and treatment of HCW. The proposed model was tested on real-scale example for the city of Belgrade.

The paper is organized as follows. In Section 2, a description of the problem, as well as a mathematical formulation for logistics network design is described. Section 3 presents the numerical example while concluding remarks are given in Section 4.

2. PROBLEM DESCRIPTION

In this paper, we considered a problem of logistics network design for HCW. The proposed model determines the locations of two types of facilities: HCW collection centers (HCWCCs) and HCW treatment centers (HCWTCs). So, on the first, lowest level of the network, there are generators of HCW such as hospitals, medical centers, dental practices, etc. On the second level of the network, there are HCWCCs while on the third level there are HCWTCs. HCWCCs are facilities with a smaller capacity than HCWTCs in which sterilization of HCW (autoclaving) is performed. Some quantities of HCW from HCWCCs end up in HCWTCs, where the incineration process takes place. In our paper, there are 17 municipalities of Belgrade city as HCW generators, 10 potential locations for HCWCCs and 3 potential locations for HCWTCs. If there are no data for HCW quantities, then usually the quantity of generated HCW can be calculated in two ways. The first one is based on the number of hospital beds and their occupancy, and the second one, which is used in this paper, is based on the average quantity of waste generated per capita and the number of residents of 17 Belgrade municipalities. The following notation was used in order to formulate a mathematical model:

Sets:

$I = \{1,\ldots, |I|\}$ - set of candidate locations for HCWCCs;

$J = \{1,\ldots, |J|\}$ - set of demand centers;

$K = \{1,\ldots, |K|\}$ - set of candidate locations for HCWTCs;

Parameters:

p – an estimated fraction of HCW that can be sent to the HCWTCs;

f_i – fixed costs for an HCWCCs at location $i \in I$;

f_k – fixed costs for a HCWTCs at a location $I \in I$;

b_i - capacity (tonnes) of HCWCCs established at location $i \in I$;

d_j - tonnes of HCW generated in demand center $j \in J$

h_k - capacity (tonnes) of HCWTCs $k \in K$

c_{ij} - transportation cost per tonne of HCW from demand center $j \in J$ to HCWCCs $i \in I$

a_{ik} - transportation cost per tonne of HCW from HCWCCs $i \in I$ to HCWTCs $k \in K$

Decision variables:

y_i - binary variable taking the value of 1 if a HCWCCs is located at location i, and 0 otherwise

s_{ij} - tonnes of HCW transported from the demand center $j \in J$ to the HCWTCs located at $i \in I$

w_{ik} - tonnes of HCW transported from the HCWCCs located at $i \in I$ to the HCWTCs located at $k \in K$

z_k - binary variable taking the value of 1 if an HCWTCs is located at location $k \in K$, and 0 otherwise

The mathematical formulation of the problem is:

$$\text{Min} \sum_i f_i y_i + \sum_k f_k z_k + \sum_i \sum_j c_{ij} s_{ij} + \sum_i \sum_k a_{ik} w_{ik} \quad (1)$$

$$\sum_{j \epsilon J} s_{ij} \leq b_i y_i, \forall i \epsilon I \quad (2)$$

$$\sum_{i \epsilon I} w_{ik} \leq h_k z_k, \ \forall k \epsilon K \quad (3)$$

$$\sum_{i \epsilon I} w_{ik} = p \sum_{j \epsilon J} s_{ij}, \ \forall i \epsilon I \quad (4)$$

$$\sum_{i \epsilon I} s_{ij} = d_j, \forall j \epsilon J \quad (5)$$

$$y_i \in \{0,1\}, \forall i \epsilon I \quad (6)$$

$$s_{ij} \in \{0,1\}, \forall i \epsilon I, \forall j \epsilon J \quad (7)$$

$$w_{ik} \in \{0,1\}, \forall i \epsilon I, \forall k \epsilon K \quad (8)$$

$$z_k \in \{0,1\}, \forall k \epsilon K \quad (9)$$

The objective function (1) minimizes the total costs of the system. Constraint sets (2) and (3) are capacity constraints for HCWCCs and HCWTCs, respectively. Constraint set (4) ensures that an estimated fraction of HCW is transported from HCWCCs to HCWTCs for further treatment. Constraint set (5) ensures that all generated HCW quantities are collected from HCW generators. Finally, constraint sets (6), (7), (8) and (9) define the nature of the variables.

3. NUMERICAL RESULTS

The model has been tested on a case study of the city of Belgrade and its 17 municipalities as HCW generators (Table 1). Fixed costs for HCWCCs are 500 €/day while fixed costs for HCWTCs are 1000 €/day. Capacities for HCWCCs and HCWTCs are sufficient and set to 10000 kg/day. In order to test the proposed model, the parameter p has three values (0.4, 0.8 and 1).

Table 1. Quantities of generated HCW

	Generators	HCW quantity (kg)	Potential locations for HCWCCs and HCWTCs
1	Zemun	2501.72	HCWCC
2	Novi Beograd	2463.98	
3	Stari grad	553.03	
4	Palilula	2072.16	HCWCC
5	Savski venac	450.17	HCWCC
6	Vračar	661.45	
7	Zvezdara	1956.16	HCWCC
8	Voždovac	1851.64	
9	Čukarica	2048.32	HCWCC (2 locations)
10	Surcin	528.01	HCWTC/HCWCC
11	Rakovica	1380.82	
12	Obrenovac	831.32	
13	Grocka	990.73	HCWTC/ HCWCC
14	Barajevo	310.96	HCWCC
15	Sopot	230.16	HCWCC
16	Mladenovac	602.84	HCWCC
17	Lazarevac	661.00	HCWTC

The model has been solved using the software tool LPSolve IDE 5.5.2.5. Results of the model testing for given input data are presented in table 2. The allocation of HCW generators to opened HCWCCs is given in table 3.

Table 2. Results of model testing

<table>
<tr><td colspan="3">p=0.4</td><td colspan="3">p=0.8</td><td colspan="3">p=1</td></tr>
<tr><td>Objective function value</td><td>Opened HCWTTc</td><td>Opened HCWCCs</td><td>Objective function value</td><td>Opened HCWTTc</td><td>Opened HCWCCs</td><td>Objective function value</td><td>Opened HCWTTc</td><td>Opened HCWCCs</td></tr>
<tr><td rowspan="6">145407.30 €</td><td rowspan="3">Surčin</td><td>Zemun</td><td rowspan="6">222347.40 €</td><td rowspan="3">Surčin</td><td>Surčin</td><td rowspan="6">257087.5€</td><td>Surčin</td><td>Surčin</td></tr>
<tr><td>Čukarica1</td><td>Čukarica1</td><td rowspan="2">Grocka</td><td>Zvezdara</td></tr>
<tr><td>Čukarica2</td><td>Čukarica2</td><td>Grocka</td></tr>
<tr><td rowspan="3">Grocka</td><td>Mladenovac</td><td rowspan="3">Grocka</td><td>Zvezdara</td><td rowspan="3">Lazarevac</td><td rowspan="3">Sopot</td></tr>
<tr><td>Zvezdara</td><td rowspan="2">Grocka</td></tr>
<tr><td>Grocka</td></tr>
</table>

Table 3. Allocation of HCW generators to HCWCCs

	p=0.4	p=0.8	p=1
HCW generators	HCWCCs		
Zemun	Zemun	Surčin	Surčin
Novi Beograd	Zemun	Surčin	Surčin
Stari grad	Zvezdara	Zvezdara	Zvezdara
Palilula	Zvezdara	Zvezdara	Zvezdara
Savski venac	Zvezdara	Zvezdara	Zvezdara
Vračar	Zvezdara	Zvezdara	Zvezdara
Zvezdara	Zvezdara	Zvezdara	Zvezdara
Voždovac	Zvezdara	Zvezdara	Zvezdara
Čukarica	Čukarica1	Čukarica1	Surčin
Surcin	Zemun	Surčin	Surčin
Rakovica	Čukarica1	Čukarica1	Zvezdara
Obrenovac	Čukarica2	Čukarica2	Surčin
Grocka	Grocka	Grocka	Grocka
Barajevo	Čukarica2	Čukarica2	Sopot
Sopot	Mladenovac	Grocka	Sopot
Mladenovac	Mladenovac	Grocka	Sopot
Lazarevac	Čukarica2	Čukarica2	Sopot

As can be seen from the results, for p=0.4 two HCWTCs and six HCWCCs are opened, while for p=0.8, two HCWTCs and five HCWCCs are opened. Although the number of opened facilities in scenario 2 is smaller than in scenario 1, the total costs of the system are higher. Namely, quantities of transported HCW on the network differ due to different values of parameter *p*, so the objective function value is higher for p=0.8. In case when p=1, when all generated HCW quantities are transported from HCWCCs to HCWTCs, the number of opened HCWCCs is smaller but all three locations for HCWTCs are opened. In this scenario, HCW isn't treated in HCWCCs, meaning that HCWCCs serve only as collection points for HCW. Also, since the fixed costs of opening HCWTCs are higher than HCWCCs, total system costs are the largest for all observed scenarios. It can be concluded that input parameters, especially generated HCW quantities and fixed costs of opening facilities, play a significant role in model testing, hence considerable attention must be given to their definition.

3. CONCLUSION

Health-care waste management has become very important, from an economic, environmental and protection point of view for all involved actors in health-care management. In this paper, an approach for designing a logistics network for the HCW was tested on a real-scale example for the city of Belgrade. Test results showed that the model is dependent on the input parameters, especially fixed costs of opening facilities as well as generated HCW quantities. Future directions of model development may include HCWCCs and HCWTCs capacity constraints, different approaches for determining HCW generated quantities, but most importantly treating the uncertainties present in obtaining input data for modeling, etc.

ACKNOWLEDGMENT

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IMPACT OF EXTERNAL TRUCKS' SERVICES AT THE PORT CONTAINER TERMINAL ON EXHAUST GAS EMISSIONS

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Abstract: *We investigated the export containers delivery process to a port container terminal (PCT) by external trucks for the purpose of loading onto container ships. Containers randomly arrive by trucks to a PCT, while they are shipped according to a predefined schedule of container ships. We analyzed the arrival and service processes of trucks at the entrance gate, inspection and unloading points. In addition, we analyzed the differences between various truck service scenarios, determined the total waiting time of trucks for each scenario and observed the impact of each scenario to the levels of emissions of exhaust gases produced by these trucks.*
Keywords*: port container terminal, truck turnaround time, emission reduction.*

1. INTRODUCTION

In recent years, we are witnessing the growth of traffic at port container terminals (PCTs), as well as the higher costs of transportation, material handling equipment and labor (Vukićević Biševac et al. 2021). The increase in the carrying capacity of container ships is affecting the phenomenon „peaks in truck arrivals for delivering or picking up a container" discussed by Lange et al. (2017).

In recent literature, little attention has been paid to the problem of congestion at PCTs, as well as the problems of pollution and long truck turnaround times that arise as a result. In recent years, a number of measures have been proposed in order to reduce queues at the entrance/exit gate and congestion within a PCT.

Previous research can be divided into two groups. The first group consists of research addressing measures to increase the number of gate lanes and the number of yard cranes.

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The second research group considers measures related to the development of a system for TAM (truck arrival management) in order to smooth the peaks in truck arrivals. These systems are most often based on tariff/toll pricing policies (TTPP), terminal appointment system (TAS) and vessel dependent time windows (VDTWs) (Ma et al. 2019).

2. PROBLEM DESCRIPTION

The paper analyzes the flow of export containers that are delivered to the PCT by external trucks and shipped out by container ships. There are often queues, both in front of the entrance gate and inside the PCT. The queues at the entrance gate impact the queues inside the terminal, which leads to congestion. Congestion affects the increase in waiting times for trucks and the consequent increase in truck turnaround times at the PCT. While waiting to be unloaded, trucks emit exhaust gases that contain numerous pollutants (CO, NOx, CO2, CH4, N2O, PM, etc.) (Jin et al. 2021; Ma et al. 2019).

Trucks arrive at the entrance gate and wait for the first free entrance ramp to enter the PCT. Once they enter, they wait for the inspection of cargo/containers. After the cargo control/inspection is completed, the truck arrives at the beginning of the container yard, which is a designated storage area for export containers in a PCT before they are loaded to the ships. The truck waits for the first available yard crane to unload the container, and then leaves empty toward the exit gate. The time from the truck's arrival (or joining the queue) at the entrance gate to leaving the PCT is called the truck turnaround time at the PCT. Figure 1 shows the flow of export containers.

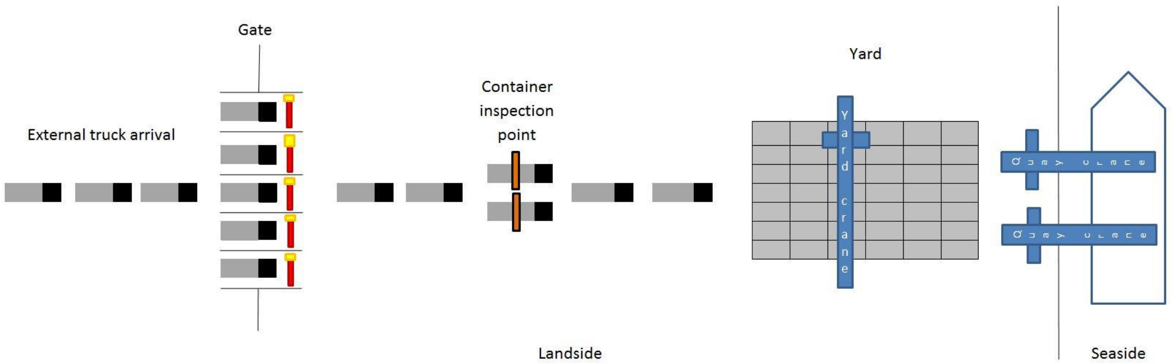

Figure 1. Schematic representation of the flow of export containers at a PCT

The PCT operator has a goal to shorten the total service time within the terminal for all users (Vukićević Biševac et al. 2021), including the truck turnaround times, and thus to reduce the pollution that occurs as a result of waiting for service.

The following chapter analyzes the impact of different arrival/service rates or intensities at the entrance gate, inspection point and unloading by yard cranes on trucks waiting times. Based on the obtained waiting times of trucks, we calculated (quantified) the corresponding pollution quantities/levels.

3. SERVICE OF EXTERNAL TRUCKS WITHIN THE 3- STAGE SERIES QUEUING SYSTEM

We implemented a discrete event simulation to study the performance of the described queuing systems at the PCT. The arrivals of trucks carrying export containers are determined by the schedule of container ships. We focused our analysis to the arrival of trucks with containers that are bound to one ship.

Ma et al. (2019) stated that the arrival of the external trucks is a non-homogeneous Poisson process that can be transformed into a piecewise-constant non-homogeneous Poisson process in time periods that are sufficiently short. Ioannou et al. (2001) stated that some ports use cutoff times for each ship, after which cargo bound to the one ship is no longer received, in order to meet ship departure schedules and operate efficiently. Ioannou et al. (2001) observed and simulated trucks' arrivals during the three days before the cutoff time. As a design consideration, Ioannou et al. (2001) used arrivals of external trucks with export containers: 0.2, 0.5 and 0.3, meaning 20% of trucks arrived during the first day, 50% arrived during the second day, and 30% during the third day.

In this paper we assumed that trucks bound to one ship arrive during the five days period. We assumed that the PCT operates for 24 hours, 7 days a week. We also assumed that the service of trucks is performed within a queuing system as FIFO (first in first out) service discipline, i.e., the first truck that arrived would be the first one served.

We assumed trucks' arrivals of 0.1, 0.15, 0.45, 0.25 and 0.05 for the five days. We assumed that trucks interarrival times were modeled by Exponential distribution (Poisson arrivals) with parameters: λ_1 = 5 trucks per hour during the first day, λ_2 = 7 trucks per hour during the second day, λ_3 = 20 trucks per hour during the third day, λ_4 = 10 trucks per hour during the fourth day, λ_5 = 2 trucks per hour during the fifth day. Using these values of arrival rates allowed us to achieve cumulative arrivals like the S-shaped curve, presented by Daganzo (2003). The PCT operator can serve approximately 1000 trucks during the five days interval, as Chang et al. (2012) stated to be the average number of containers loaded on one ship in a PCT.

Service times at three stages (phases) in the PCT were modeled as follows:

• Phase I is a service performed at an entrance gate. We assumed that the service time at an entrance gate is exponentially distributed with the parameter μ_1.

• Phase II is a service performed at an inspection point. Yoon (2007) analyzed service time at the PCT inspection point and stated that it is exponentially distributed. Service time at phase II is exponentially distributed with the parameter μ_2.

• Phase III is a service performed by a yard crane. According to Petering et al. (2008) the time taken by a yard crane to handle a single container can be modeled by a triangular distribution. The service time of a yard crane is modeled by a triangular distribution with parameters (μ_{3a}, μ_{3b}, μ_{3c}), where μ_{3a} equals the smallest, μ_{3b} equals the most often (mode) and μ_{3c} equals the largest service rate.

3.1 Simulation results

The simulation was performed using Microsoft Excel with trucks' daily arrival rates λ_1, λ_2, λ_3, λ_4 and λ_5 (as described in the previous section) and the total of 1036 trucks arrived during the simulated five days period. Using the same arrival rates we simulated trucks' service within the PCT with different service rates in individual phases of service μ_1, μ_2, μ_{3a}, μ_{3b} and μ_{3c} (the values are given in Table 1 below). Values for varying μ_2 correlate with service rates at inspection point given by Yoon (2007).

We recorded the following: the arrival times of trucks at the entrance gate, the waiting time in front of the entrance gate, the moments of entrance and waiting times for each phase of service, as well as the moments of exit from the last phase of service.

The average trucks waiting times W_{qi} in individual phases of service depending on the service rates μ_i, i = 1, 2, 3 are shown in Table 1. From the obtained results it can be noticed that when the service rates are increased, the waiting times W_{q1} and W_{q2} are decreased, and the waiting time W_{q3} is increased. Also, it is interesting to notice the results of the scenarios 7, 7a and 7b. In these scenarios only the service rate μ_2 increases. Comparing the scenarios 7 and 7a we can see that W_{q1} is the same, W_{q2} decreases and W_{q3} increases. The similar conclusions can be done comparing the scenarios 7a and 7b, as well as 8 and 8a.

Table 1. Average waiting time per truck

<table>
<tr><th>Scenario</th><th>μ_1 [truck/h]</th><th>μ_2 [truck/h]</th><th>μ_{3a} [truck/h]</th><th>μ_{3b} [truck/h]</th><th>μ_{3c} [truck/h]</th><th>W_{q1} [h]</th><th>W_{q2} [h]</th><th>W_{q3} [h]</th></tr>
<tr><td>1</td><td>12</td><td>12</td><td rowspan="12">17.6</td><td rowspan="12">30</td><td rowspan="12">50</td><td>5.4737</td><td>2.9216</td><td>0.01046</td></tr>
<tr><td>2</td><td>15</td><td>15</td><td>1.7421</td><td>2.0360</td><td>0.0136</td></tr>
<tr><td>3</td><td>16</td><td>16</td><td>1.1144</td><td>1.5841</td><td>0.01516</td></tr>
<tr><td>4</td><td>17</td><td>17</td><td>0.6665</td><td>1.1906</td><td>0.01628</td></tr>
<tr><td>5</td><td>18</td><td>18</td><td>0.3468</td><td>0.9500</td><td>0.01738</td></tr>
<tr><td>6</td><td>19</td><td>19</td><td>0.1823</td><td>0.6820</td><td>0.01885</td></tr>
<tr><td>7</td><td rowspan="3">20</td><td>20</td><td rowspan="3">0.1093</td><td>0.4143</td><td>0.0211</td></tr>
<tr><td>7a</td><td>21</td><td>0.2819</td><td>0.02291</td></tr>
<tr><td>7b</td><td>22</td><td>0.1927</td><td>0.02536</td></tr>
<tr><td>8</td><td rowspan="2">21</td><td>22</td><td rowspan="2">0.0832</td><td>0.1936</td><td>0.02516</td></tr>
<tr><td>8a</td><td>23</td><td>0.1337</td><td>0.02675</td></tr>
<tr><td>9</td><td>22</td><td>23</td><td>0.0680</td><td>0.1308</td><td>0.02665</td></tr>
</table>

Figure 2 shows the cumulative diagrams of arrival and service of external trucks at the PCT. We can observe the formation of queues before the first and the second service phases; we do not observe large queues in front of the third phase.

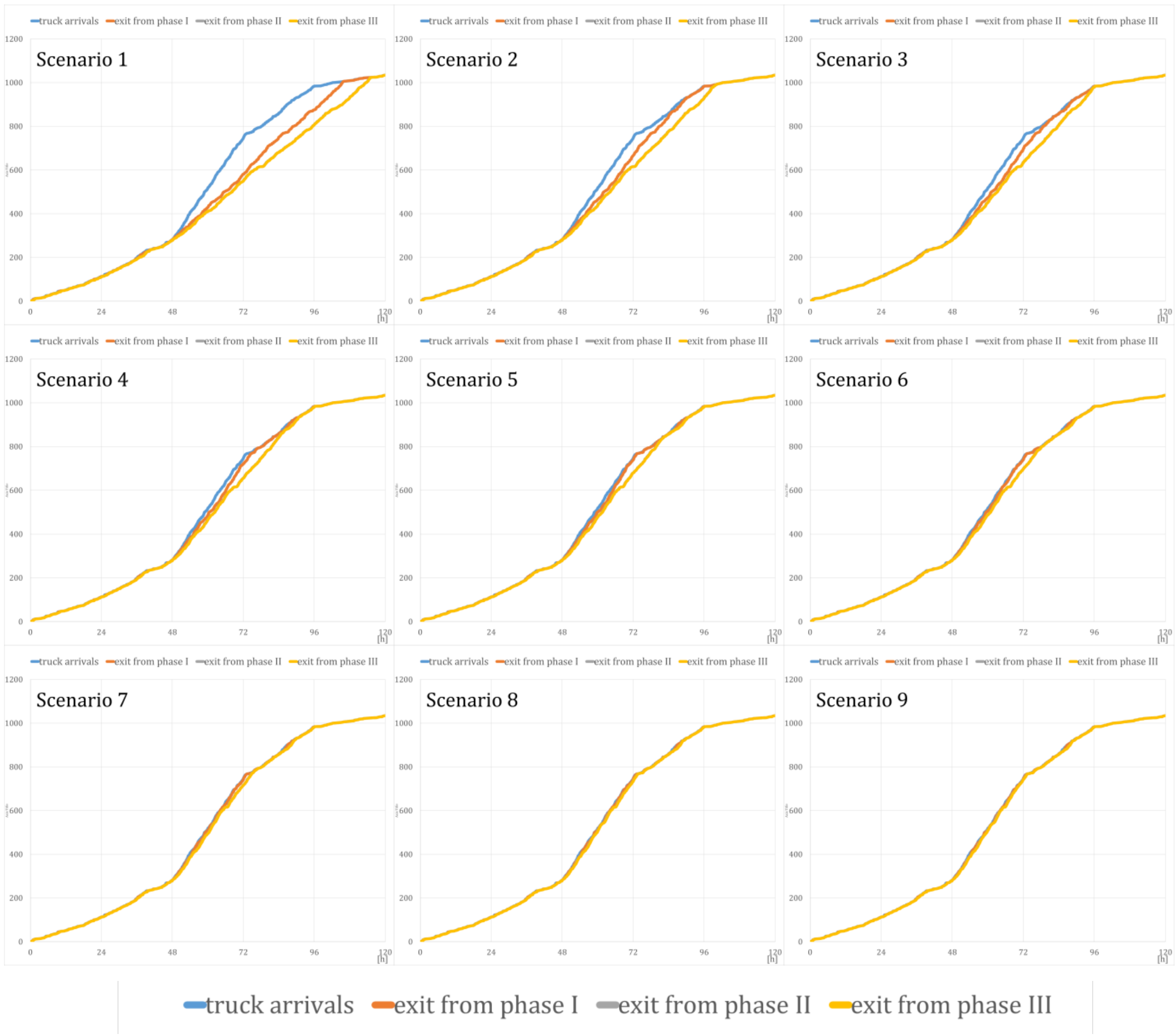

Figure 2. Arrivals and service within three phases for various scenarios

4. COST OF CARBON EMISSIONS GENERATED BY TRUCKS AT THE PCT

During the five simulated days the total of 1036 trucks delivered export containers. The total waiting time (W) for all 1036 trucks is calculated as given in (1) and presented in Table 2.

$$W = W_1 + W_2 + W_3 = 1036\,(W_{q1} + W_{q2} + W_{q3}) \tag{1}$$

Jin et al. (2021) calcualted carbon emissions generated by one truck in each second based on the data recorded in container ports in Southern China for 83582 trucks (as given in (2)).

$$e = sp + (wav + 0{,}5C_d A\rho v^3 + wgC_r cos\theta v + wgvsin\theta v)/\varepsilon\eta \tag{2}$$

where:

$s -$ specific fuel consumption, $p -$ engine power, $v -$ average speed, $w -$ average weight, $a -$ acceleration , $\rho -$ air density, $\theta -$ angle of slope, $A -$ frontal surface area of the truck, $g -$ gravity, $C_r -$ coefficient of rolling resistance, $C_d -$ coefficient of drag, $\varepsilon -$ truck drivetrain efficiency, $\eta -$ efficiency of engine.

Then, based on the calculated carbon emissions generated by trucks in each second and the price of carbon per Kg (estimaed by Ricke et al. 2018), they obtained an average carbon emissions cost per hour (C), which equals USD 1,348 per hour for external trucks.

Based on the total waiting time (W) obtained by the simulation and the average carbon emission cost (C), we calculated the total cost of carbon emissions ($EC = W \cdot C$) for all scenarios. These costs are given in the last column of Table 2. Comparing the scenarios 1 and 2 we can notice that when μ_1 and μ_2 are increased from 12 to 15 trucks per hour the total cost of carbon emissions decreased for more than 50% $\left(\frac{11738.88-5295.22}{11738.88} \cdot 100\ \%\right)$. Also, comparing the scenarios 2 and 3 we can see that the total cost is decreased for 28.4%. The trend of decreasing of the total cost continues to the last scenario, which has the total cost of 314.85$.

Table 2. Total cost of carbon emissions for each scenario

Scenario	W_1 $[h]$	W_2 $[h]$	W_3 $[h]$	W $[h]$	EC $[USD]$
1	5670.75	3026.78	10.84	8708.37	11738.88
2	1804.82	2109.30	14.09	3928.20	5295.22
3	1154.52	1641.13	15.71	2811.35	3789.70
4	690.49	1233.46	16.87	1940.82	2616.23
5	359.28	984.20	18.01	1361.49	1835.29
6	188.86	706.55	19.53	914.94	1233.34
7	113.23	429.21	21.86	564.31	760.69
7a		292.05	23.73	429.02	578.32
7b		199.64	26.27	339.14	457.17
8	86.20	200.57	26.07	312.83	421.70
8a		138.51	27.71	252.42	340.26
9	70.45	135.51	27.61	233.57	314.85

5. CONCLUSIONS

We analyzed the impact of different service rates or intensities of entrance gate, inspection point and yard cranes on waiting times of trucks, as well as on pollution that occurs as a result of waiting.

Based on the obtained results, we can conclude that even with a small increase in the intensity of service at the entrance gate and the inspection point, the emission of harmful gases from external trucks can be significantly reduced. Large investments are not required in order to shorten the service and waiting times of trucks. Increasing the intensity of service is also possible by changing some procedures at the entrance gate or by implementing new technologies at the inspection point.

In this paper, we only analyzed the incoming flow of trucks/containers to the PCT. The congestion at the PCT can as well be influenced by the trucks transporting import containers from the PCT. Our future research will include both directions, as well as congestion due to the flow of trucks within the PCT.

ACKNOWLEDGMENT

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APPENDIX A

[$s = 70$ g/kw. h, $p = 220$ kw, $v = 5\ km/h$, $a = 0\ m/s^2$, $\rho = 1{,}293 kg/m^3$, $\theta = 0°$, $A = 4\ m^2$, $g = 9{,}788\ m^2/s$, $C_r = 0{,}012$, $C_d = 0{,}9$, $\varepsilon = 0{,}9$, $\eta = 0{,}45$]

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PART IV

SCM, LOGISTICS 4.0 INFORMATION TECHOLOGIES IN LOGISTICS

SOME SPECIFICS OF SUPPLY CHAIN MANAGEMENT IN POST-COVID PANDEMIC – 19 ERA

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Abstract: *The outbreak of the COVID-19 pandemic caused major disruptions in all parts of the supply chain. Due to the increased vulnerability at all levels of business, it is necessary to suggest appropriate supply chain management strategies. As the pandemic is expected to end, identifying the main obstacles to the recovery of the supply chain is necessary for its survival and competitiveness in the market. The goal is to ensure the efficient functioning of the supply chain in the post-COVID-19 period. This research aims to examine some specifics of supply chain management to mitigate the consequences of disruptions caused by the current pandemic. This paper analyzes some of the challenges in supply chain management recovery, including how some companies have responded to disruptions during the pandemic. Some of the supply chain models that would further contribute to improving its sustainability after the pandemic were also discussed.*

Keywords: *SCM, recovery, post COVID-19 era, challenges.*

1. INTRODUCTION

The global spread of the COVID-19 pandemic, which began in late 2019, has brought the problem of supply chain (SC) resilience into the focus of much research. SC represents a network of interdependent business entities, i.e., a set of relationships between suppliers, manufacturers, and distributors that are organized to achieve the flow of materials, finished products, information, and money (Ivanov, 2020). Increasing SC resilience can be achieved by implementing appropriate management strategies. Supply Chain Management (SCM) is the organization and coordination of goods and service flows and encompasses all processes that transform raw materials and semi-finished products into finished commodities (Ivanov, 2020; Sabouhi et al., 2021). It includes the rationalization of a company's operations to meet customer requirements, gain a competitive advantage in the market, and enable a continuous flow of all goods.

The outbreak of the pandemic significantly affected the resistance to SC. Under the current conditions, many negative consequences have occurred in terms of finances, goods delivery, customer service, production performance, and so on. Effective SCM

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solutions are required to limit these consequences. The COVID-19 pandemic has caused significant disruptions in the SCM. Moritz (2020) points out a few key characteristics of the current crisis that set it apart from other common disorders in SC. So far, most of the disruptions are very restricted in their impact, extending largely through one region of the world. However, the pandemic has spread worldwide. When industrial plants were forced to close due to the pandemic, it had a significant impact not only on the availability of these commodities but also on the entire SCM. It also had an impact on demand as many retailers, restaurants, and other service providers were forced to close for some time until stricter precautions were put in place. The pandemic's length and scope are unknown, which distinguishes it from other disruptions that have had a substantial impact on SCM and almost all SC entities (Sabouhi et al., 2021; Moritz, 2020). In order to gain insight into the disruptions caused by the COVID-19 pandemic, Figure 1 shows the consequences of some of them that occurred in previous years.

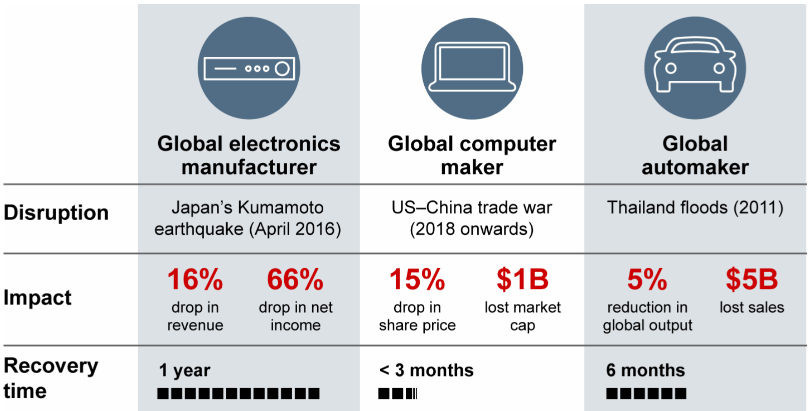

Figure 1. Characteristics of past years' disruptions (Sabouhi et al., 2021)

The earthquake that occurred in Japan in 2016 led to a drop in total revenue of 16% and a 66% reduction in net income in electronics manufacturing. The period needed for Japan to recover from this crisis is one year. When it comes to the crisis in the trade of computer equipment between the US and China, there was a drop in the value of shares by 15% and a loss of 1 billion dollars in the Chinese market. In these conditions, it took China a little less than 3 months to overcome this crisis. The flood in Thailand caused a crisis in the automotive industry. The consequences were: 5 billion dollars lost due to unrealized sales and a 5% drop in car exports in the global market. In this crisis, it took the economy 6 months to recover from all the disturbances. The presented data on individual crises that occurred earlier is aimed at showing that in the COVID-19 crisis, the consequences for the market and SC will be significantly greater than before. As the pandemic has been going on for 2 years, the time required for the entire global economy and the SC to completely recover will be significantly longer than it was during the previously described disruptions (Sabouhi et al., 2021).

In order to maintain the business continuity of companies and the competitiveness of SCs in strict market conditions, the imposed challenges must be treated as current obstacles, by overcoming which SCM becomes more resilient. This paper analyzes some of the solutions implemented by certain companies to make the associated SC sustainable. Clearly, the COVID-19 pandemic has created a new business environment. As current challenges will be present in the post-COVID-19 era, the purpose of this paper is to point out some of the many trends of current SCM models.

2. CHALLENGES IN COVID-19 PANDEMIC RECOVERY

Some of the numerous recent studies have highlighted actual problems for SC in recovering from the COVID-19 pandemic, either directly or indirectly. According to analyzed studies, the COVID-19 pandemic might have detrimental and long-term consequences for companies and the global economy (Ivanov, 2020; Lalon, 2020; Majumdar et al., 2020). For a long time, it was believed that the financial crisis would cause significant changes in the SCs' companies. This crisis will have an impact on end-user demand for some products, such as clothing, electronics, and luxury goods (Lalon, 2020; Majumdar et al., 2020). During the recovery phase, manufacturers of these products will experience order cancellations and delayed payments from customers. As a result, it will take longer for these SCs to recover from the pandemic. Furthermore, because of the severity of the crisis, companies are likely to be impacted for a long period of time. Also, many companies may go bankrupt due to the impact of COVID-19, which will cause difficulties in allocating resources to implement SCM recovery strategies (Majumdar et al., 2020; Choi, 2020).

Numerous research studies on the current COVID-19 pandemic have identified the effects and challenges that significant pandemics have on SC operations. For example, Ivanov (2020) discusses the impact of a pandemic on demand, production, supply, and other processes in the SCM at the same time. Given the numerous consequences of the COVID-19 pandemic, SCM recovery models must address all of them simultaneously. The complexity of SC activities is expected to rise as a result of careful consideration when developing recovery solutions (Ivanov, 2020; Choi, 2020). For SC and SCM, increasing entities' capacity and continuous flows of materials, energy, and information are key challenges in the post-pandemic period. Comprehensive and effective strategies need to be introduced, as coordination and horizontal cooperation between producers at the national level within the SC are needed. Companies are also facing threats of closure due to temporary blockades in the countries where their key partners in the SC operate.

SC and SCM in the post-COVID-19 era characterize companies that have faced an economic crisis, reducing production capacity, limiting institutional support and other societal challenges in the medium or long term. Moreover, some SC partners may suspend their activities if they are unable to absorb the loss from disruption (Lalon, 2020). This will present many challenges in the recovery phase. For example, companies could be forced to purchase materials at higher prices because of a shortage of suppliers. As a result, new partnerships in the SC should be developed, which will affect the current cooperation and partnerships (Paul et al., 2021).

Recovery decisions making SCM are a major challenge that has been discussed in the literature (Ivanov, 2020; Lalon, 2020; Majumdar et al., 2020; Choi, 2020). Even though companies have encountered several major outbreaks in the past, the current COVID-19 pandemic is far more severe than prior outages. As a result, there has been a lack of capacity to deal with such a pandemic, which will cause delays in decision-making (Van Der Hoek et al., 2020). SCs are expected to have difficulty implementing quick recovery plans and strategies because of weaknesses in infrastructure, digital technologies, and resources. Many issues suggest that recovering from the COVID-19 pandemic will be challenging, requiring comprehensive research into all potential problems while respecting the economic, ecological, and social pillars of SCM (Gurbuz & Ozkan, 2020; Leite et al., 2020; Sharma et al., 2021).

Table 1. SCM challenges in the post-COVID-19 period

Authors	Challenges
Choi (2020)	The bankruptcy of partners in SC.
Garbuz et al.(2020)	Layoffs in the industry, the renewal of SC networks, and difficulties in maintaining relationships.
Leite et al. (2020)	Lack of resources to implement a rapid recovery plan and difficulties in increasing production capacity.
Sharma et al. (2021)	Low level of preparedness, inadequate infrastructure, and resources.
Sharma et al. (2021)	Demand disruption, implementation of dynamic response and the latest technologies, SCM reconfiguration, and synchronization process.
Van Der Hoek et al.(2020)	Flexibility and the possibility of the adoption of new distribution models and digital technologies are limited.

Table 1. summarizes many important challenges in SCM's recovery from the COVID-19 outbreak. Based on Table 1, which lists only some of the key challenges, it is concluded that their list is not complete. The possibilities of company bankruptcy, lack of resources and disruptions in demand, as well as layoffs, clearly indicate that the current conditions will maintain the status quo and cause other challenges that must be effectively addressed in order to succeed and sustain the sustainability of SCM.

3. SCM - EXAMPLES OF GOOD PRACTICE AT THE TIME OF COVID-19

The efficiency of SCM plays a key role in improving the financial performance of companies, which is directly related to meeting customer requirements through the delivery of products and services. It is also a crucial factor in lowering procurement, transportation, and delivery costs. Costs incurred as a result of unfulfilled deliveries were unavoidable during the pandemic. However, some companies have established sustainable strategies to mitigate losses incurred as a result of the new business environment. Amazon and Johnson & Johnson are just two examples that will be discussed below (Van Der Hoek et al., 2020; Leite et al., 2020).

3.1 Flexibility in Amazon delivery

Amazon is an American multinational technology company based in Seattle, Washington that has a focus on e-commerce, cloud computing, and artificial intelligence, as well as

other Industry 4.0 solutions. Specifically, Amazon is the largest electronic marketplace and cloud computing platform in the world, measured by revenue and market capitalization. This major world trade network faced incredible obstacles in early 2020, partly due to growing global demand and partly as a result of quarantine due to the COVID-19 pandemic. Despite many challenges in a short period of time, Amazon's SCM has been successful in solving a number of problems at all levels of customer service. At the moment when the countries were locked down, i.e., the borders were closed, the transport stopped and many deliveries were not delivered on time (Ivanov, 2021).
Amazon then showed its strongest link, and that is flexibility. At that moment, their SCM had to adapt to the new situation to find a way to fulfill their goal, which was to satisfy the end-user. Amazon's SCM has taken over the cost of delayed delivery. The company has made changes to its business model to prioritize the storage and delivery of all deliveries that were delayed during the pandemic, including those related to the delivery of medical care and household necessities, as well as basic foodstuffs. Adjustment measures have enabled the distribution of goods, allowing Amazon to meet its primary goal of meeting customer requirements (Ivanov, 2020; Ivanov, 2021). Another strategy used by the corporation to avoid supply delays during the pandemic was to go entirely online. During the current pandemic, Amazon also opened plants dedicated solely to internet commerce. As a result, the company was able to increase its delivery capacity. By modifying its business model, Amazon nearly doubled the capacity of its grocery delivery service from March to September 2020, resulting in increased profits (Figure 2).

Figure 2. Amazon's sales and profits grow in 2020 (Ivanov, 2021)

Furthermore, to protect employees and customers, health and safety measures against the COVID-19 pandemic have been developed at their physical collection sites. To adapt to current conditions, many stores have also adopted a new manner of working. For example, during certain parts of the day, they provided services to the elderly and users with special needs, as well as high-risk groups (Ivanov, 2021). These conditions affected the increase in Amazon sales that continued in 2021, as shown in Figure 3.

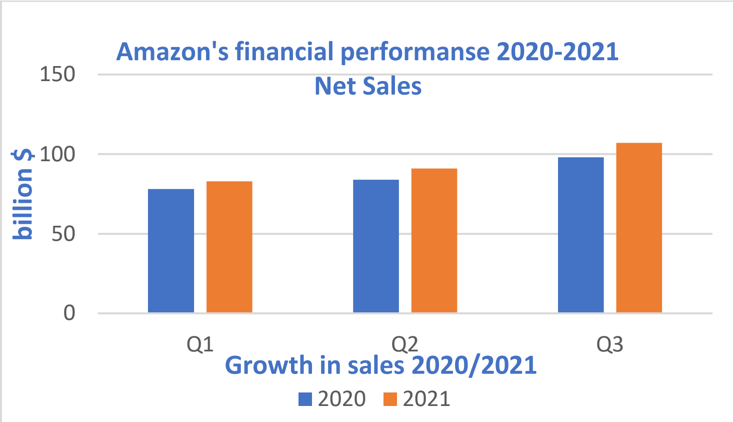

Figure 3. Amazon's growth in sales for 2020–2021 (Ivanov, 2021)

Based on Figure 3, it was observed that there was an increase in sales volume of 6.5% to more than 8% in the first and second quarters, respectively. This increase was about 9.5% higher in the third quarter of 2021, which indicates the effectiveness of Amazon's SCM in post-COVID-19 conditions. Furthermore, accepting costs for delivery delays at the start of the pandemic resulted in a revenue boost during the COVID-19 pandemic (Ivanov, 2021).

3.2 Flexibility in supply - Johnson & Johnson

Johnson & Johnson is a leading international company engaged in the production of drugs, medical devices, and related products. As a result of its response to the COVID-19 pandemic, Johnson & Johnson has provided SCM sustainability. This SC has been disrupted due to demand for a quick response from its SC in the past, giving SCM valuable expertise in circumstances like pandemics (Ivanov, 2021).

Thanks to the activities of Jonson & Jonson, the increase in demand for its paracetamol-based painkiller has doubled, and Tylenol. Although there was a temporary scarcity of this medicine, the SC worked promptly to increase product supply, allowing manufacturing and other sectors to expand their capacity. Following the pandemic's spread in Italy, SCM responded to many challenges related to customer satisfaction. Besides, Johnson & Johnson modeled possible scenarios based on actual data on the number of employees and regular production volume to protect itself from production delays due to staffing issues.

Based on the outcomes of applied quantitative models, company management was able to estimate the impact of disruption and identify potential SCM areas for modification. The company was able to use risk simulation technologies to determine the appropriate quantity of raw material orders and avoid the implications of ordering greater or smaller quantities (Ivanov, 2020; Ivanov, 2021).

Visibility of the situation of inventory in the SC is always critical for the supplier of crucial drugs, especially during the pandemic. To track common order patterns and discover major discrepancies, Johnson & Johnson deployed digital technologies and advanced algorithms. As a result, the deliveries had track and trace sensors attached, which could also measure the temperature and product quality (Lalon, 2020; Majumdar et al., 2020). This continual visibility into the whereabouts of the package also aided the company in coordinating delivery, particularly during the pandemic when numerous bans and limitations were in effect. For example, smart glasses technology enables employees to

see and access information through the glasses of another person on the spot and also extract data (Majumdar et al., 2020; Paul et al., 2021; Van Der Hoek et al., 2020).
Thanks to those and similar technologies, the company can continue functioning without interruption. Some of the company's product lines are also included in other locations around the world. The company also produced hand sanitizers for its staff as well as for the health centers in these facilities (Ivanov, 2021).
Of the many performances, Jonson & Jonson and Amazon focus more than half of their efforts on flexibility, inventory, and customer service. Customer requirements cannot be met unless products are available in warehouses. In addition, when the SCM is not flexible, it cannot respond to user requests. Due to the high level of internal flexibility, Amazon and Jonson & Jonson were able to provide a sustainable SCM to meet stochastic user requirements. In that way, these companies have also become more resilient, especially in terms of the conditions of the current pandemic (Sabouhi et al., 2021; Ivanov, 2021).

4. SCM SPECIFICS AFTER COVID-19 CONDITIONS

Before the COVID-19 crisis, trade tensions rose due to rising import duties between Washington and Beijing (Remko, 2020). Rising costs and the emergence of other financial barriers bring with them many challenges for SC. The main goals of almost every SCM are to minimize delivery time and provide service at the lowest price. However, political developments and now the global pandemic have revealed the weakness of the current production models. The hidden costs related to dependence on a single source and the lack of flexibility in adapting to real-time disturbances has come to the fore. As a result, the change that has already begun in the SCM towards greater flexibility will be significantly accelerated. In the coming years, a reconfiguration of the SCM is predicted based on three dimensions, discussed below (Buatois & Cordon, 2020; Remko, 2020).

4.1 From globalization to regionalization

The regionalization of logistics hubs is one of the goals of flexible and sustainable SCM in post-COVID-19 conditions. The problem is that China is almost the only source of material supply, which was a condition for increasing the costs of all new SCs. The difference in labor costs between Asia and Europe, which used to be a great attraction for companies, has narrowed significantly in recent years. However, China's developed network of suppliers continues to attract global interest from many companies (Ivanov, 2020; Remko, 2020).

The world's major electronic equipment manufacturers procure about 40% of their parts from China (Remko, 2020). Returning to regional SCs is a major challenge in terms of procuring the necessary parts. Given the incredibly large number of required parts of electronic equipment, each of them needs different delivery time. However, this challenge might be worth accepting in the world after COVID-19. An example that justifies the transition from a global to a regional SC is the high share of global procurement in the pharmaceutical industry in Europe. During the pandemic, Europe imported 80% of the active components of drugs from China and India. In the future, more precisely in the post-COVID-19 era, it is quite expected that European governments will ensure that these supplies can be drawn from their region. This would lead to a meaningful shift to regional sources of supply (Buatois & Cordon, 2020).

4.2 Supply chain as a new protagonist

Due to the economic crisis of 2008, the balance sheets of financial institutions around the world were analyzed from the aspect of their readiness for recession. Companies have been obliged to assess their cybersecurity systems after a series of big cyber-attacks over the last 10 years. SC resistance evaluation will become the new standard across the globe following COVID-19. In the post-COVID-19 period, the current global business model, which is optimized for low costs, will not be used. New business situations necessitate new optimization priorities. SCM activities have taken the lead in all aspects of the company's operations (Remko, 2020).

Due to the consistency of production volume, SC has traditionally been able to provide a high level of customer service while reducing delivery costs and maintaining acceptable quality. SC, SCM, and production facilities provide limited flexibility in volume. As a result, production changes have a notable impact on the entire SC. As expected, the largest suppliers and logistics operators must have such a SCM that will ensure the smooth implementation of all activities in the service of customers in disaster conditions such as fires, floods, tsunamis, pandemics, strikes, civil unrest, etc. (Buatois & Cordon, 2020).

4.3 Human resources

The human factor is back in focus again and it will be a critical pillar in rebalancing the global SC during and after this crisis. Statistical models are rendered ineffective by significant and unexpected changes in production volume. They categorize events like the pandemic as "unusual" and, therefore, exclude them from being generators of valuable information. Although visibility is required for SC entities to make choices, the majority of decisions must be made manually. In conclusion, the human factor is critical. The "autonomy" idea (automation with personal interaction) pioneered by Toyota has proven to be the most adaptive. This comprises automation of around 80–90% of the system while allowing 10–20% of human experience to improve system performance (Ivanov, 2020; Remko, 2020).

As the world's unemployment rate raises, the health and agricultural industries, as well as grocery stores and other key areas of "core business," are facing labor shortages. Amazon has announced 100,000 new positions in manufacturing centers, many of them in China. The return of quarantined employees to manufacturing plants and factories has brought relief to the West. Similarly, despite the positive impact of artificial intelligence on efficient e-commerce, the "last mile" of delivery from the distribution center to the doorstep still requires a human driver or drone operator. Working should be controlled as a fundamental mode of adjustment that is integral to the crisis response strategy. For example, to accommodate the demand for N95 masks, new manufacturing facilities are required. A larger workforce is required to start a new production line or modify an existing one. COVID-19 has exposed the flaws in the global manufacturing system, demanding a revision of the SC to respond to market demands. Post-COVID-19 goals of companies would make SC regional, change the existing SCM as a significant driver of business and strengthen the social pillar of sustainable SCM so that employees will be the key to its competitiveness (Sharma et al., 2021).

5. CONCLUSION

The COVID-19 pandemic has caused disruptions at all levels of business and society. Based on the conclusions of the paper, the great complexity of the functioning of the SCM in the conditions of a pandemic can be noticed. In addition, it can be concluded that the consequences and time required for the recovery of SC and SCM will be significantly longer than the interruptions that occurred in previous years (such as earthquakes in Japan, floods in Thailand, etc.). As the pandemic made new business conditions, companies had to find a way to adapt to the new situation. Examples are Amazon and Johnson & Johnson. The mentioned companies managed to adapt their businesses to the conditions of the pandemic thanks to their flexibility, which was discussed in the paper. To meet customer requirements, Amazon had to bear the cost of delayed deliveries. It should be noted that the COVID-19 pandemic significantly affected changes in consumer behavior and global economic conditions.

Continuous monitoring of trends in ordering enables the identification of potential generators of distortions in customer requirements. Therefore, Johnson & Johnson applied digital technology and sophisticated algorithms to make the delivery location transparent to all entities in the SC. In this way, the company provided conditions for the coordination of participants in the delivery of goods, especially during the pandemic.

The paper analyzed some typical potential obstacles and challenges in the recovery of SCM from the current crisis. The literature review identified the main obstacles, namely the bankruptcy of SC partners, inadequate infrastructure and resources, a lack of resources to implement a short-term recovery plan, and a low level of readiness for digital technology implementations. Future SCM trends are mainly driven by the return of SC from the global level to the regional level and the return of employers to the main role in the management of all processes. These are the only basic conclusions that this research provided as directions for future research. It should be noted that the real picture will only be clearer when the pandemic is completely over. The conclusion is that the approach to SCM will be completely different than before the pandemic. It is ungrateful to predict how long it will take for the SC to fully recover, which will result in significant changes at all levels of the SCM.

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SUPPLY CHAIN RISK MANAGEMENT IN COVID – 19 PANDEMIC

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Abstract: *Uncertainties, vulnerabilities, breaks, supply and delivery problems, etc., are some of the characteristics of today's supply chains. Appropriate management, with special emphasis on risk, is required for the success of the supply chain. Risk management is a particular segment of supply chain management that aims to reduce vulnerability and increase the resilience of all its entities. The COVID-19 pandemic has significantly contributed to an increase in the number, types, and volume of risks in supply chains. To ensure the sustainable functioning of the supply chain, it is necessary to formulate appropriate risk management strategies in the current pandemic. This paper aims to identify and recapitulate some of the key risks in the pandemic and to suggest ways to manage them to increase the resilience of all entities in the supply chain. Special attention is paid to the analysis of these risks to mitigate the consequences of their outbreak.*

***Keywords**:* COVID-19 pandemic, SCRM, breaks, vulnerable, risks.

1. INTRODUCTION

Stochastic requirements of users and markets, the establishment of strategic partnerships between providers of logistics and other activities, economic, energy, and information transactions, and shorter product life are just some of the causes of the company's exposure to supply chain risks (SCR). These risks can be the result of man-made disruptions or natural disasters and can have major consequences for the company. Lately, within the SCR literature, supply chain risk management (SCRM) has become a key area of interest. SCRM aims to develop a strategy for identifying, assessing, treating, and monitoring SCR. Risk management can be defined as a complex function that aims to identify, assess, and manage them in such a way that the risks related to their realization are minimal. As time goes on, SCRM practice is based on reducing the vulnerability of SC and mitigating the impact of the disorder (Wijaya, 2021; Ivanov, 2018).

The emergence of risks due to the COVID-19 pandemic affects companies and government institutions that are equally responsible for resolving disruptions. It is undeniable that strict societal constraints in dealing with the transmission of COVID-19 significantly affect

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consumer behavior and purchasing power. As a result, a significant number of companies have difficulty due to reduced traffic, which is associated with lower customer demand. Similarly, COVID-19 has caused significant uncertainty in the realization of financial activities in tourism, travel, catering, supply chains, consumption, production, etc. Furthermore, the COVID-19 crisis has had an impact on all product prices, including fossil fuels and renewable energy sources.

Many companies have temporarily stopped functioning due to bankruptcy and a lack of capital flexibility to face uncertainty during the pandemic. During the COVID-19 crisis, consumers behaved in a similar way as during historical crises, such as the 2002–04 SARS outbreak, the 2011 Christchurch earthquake, and Hurricane Irma 2017. COVID-19 significantly affects changes in user behavior, affecting global economic conditions too. This results in significant economic downturns, company and industry failures, as well as increased unemployment and flooding, especially in undeveloped economies (Wijaya, 2021).

In a competitive market environment, effective SCRM is a critical issue for a company's growth and survival. Therefore, the primary goal is to consider the possibilities for SCRM recovery in context, defining necessary measures and recommendations for overcoming the negative effects caused by the pandemic. After identifying the risk, it is desirable to consider and define a strategy that will best manage the disturbances and build greater resilience for the entire SC. Various SCRM methods and strategies can be used to increase SC resilience, as can modern tools, methods, and modern technologies (e.g., Blockchain, Big Data, Digital Twin) (Wijaya, 2021; Ivanov, 2018).

The concept of SCRM and the impact of the COVID-19 pandemic will be explained at the start of the paper. The importance of risks for SCs, their classification, and some common issues within SCRM will also be discussed. The risks to which SCs were vulnerable during the pandemic are detailed below, with a focus on risks related to supply and demand and coordination of activities in customer service. The processes of implementing these procedures and techniques, including future research directions in the context of risk management strategies, will be analyzed due to the complexity of SCRM.

2. SUPPLY CHAIN RISK MANAGEMENT

An SCR is an activity that can disturb the flow of information, materials, or finished products from producers to consumers. In essence, there are several dimensions to risk. According to some researchers, risks in SC can be categorized as operational risks and risks of disruption (Ivanov, 2018). Operational risks relate to common disruptions in SC activities, such as delivery times and fluctuations in demand. Risks of disruption mainly relate to road phenomena that have a major impact on companies (Hosseini et al., 2019). Pandemics are a special type of risk in SC since they are long-term, unpredictable, and have a wide distribution (Ivanov, 2020). Disturbances caused by pandemics can endanger the resilience of the SC and affect its recovery. SC recovery is essential for SCRM and the sustainability of SC (Son et al., 2013). Sustainability refers to "the ability of an SC to sustain and survive in a changing environment for the company."

Some of the current studies indicate that SCRM is becoming an increasingly important topic in research. Also, SCRM is a concept that encompasses all strategies, benchmarks, knowledge, processes, and technologies that can be used at both operational and strategic levels to minimize SCR. A review of the literature on this topic concludes that the authors most often apply proactive and reactive measurements for effective SCRM. Proactive measurements are used to reduce the likelihood of risky events occurring (Chen et al., 2015; Chowdhury et al., 2019). Reactive are established to reduce the impact of risks and ensure a rapid recovery of SC. Reactive measurements can be used to respond to disturbances caused by disease outbreaks, earthquakes, and terrorist attacks because their occurrence is unpredictable and beyond the control of business entities (Ali et al., 2019).

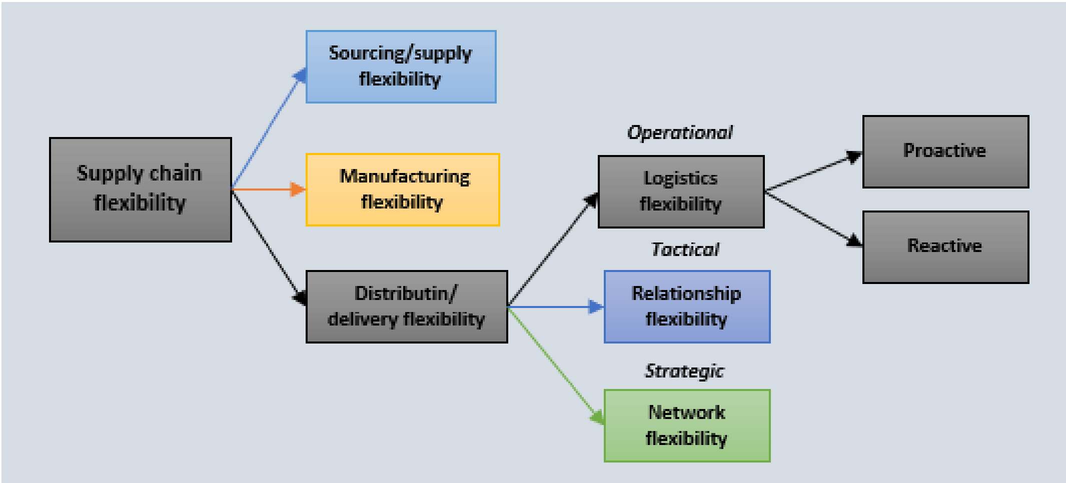

Figure 1. Implementation of proactive and reactive policies (Chen et al., 2015)

As indicated in figure 1, the implementation of proactive and reactive measurements has a direct impact on the flexibility of the entire SC. Their application is inextricably linked to operational flexibility. Through the operational level, further connection extends to the flexibility of the distribution process, i.e., product delivery. Flexibility at this level was critical in the SC during the pandemic. As significant limits were imposed by the crisis, distribution had a significant effect on meeting customer demands (Chowdhury et al., 2019; Ali et al., 2019).

The results of some previous research indicate that 80% of companies within two years of the interruption failed to formulate and implement recovery strategies due to SC disruptions during the pandemic. Based on analyzed statistics, the incidence of such major disorders in SC has increased in recent years. The development of strategies for the recovery from major pandemics has become a key factor for the long-term survival of SC. The available literature on major epidemics mainly addresses SC issues of providing humanitarian assistance in the event of outbreaks of such disturbances or other natural disasters. There is a lack of studies on how traditional SCs can recover from natural disasters. Most studies to date have focused on the development of a recovery model after an SC break. These recovery models focus on supply, production, demand, and transportation disruptions. Although the development of a recovery model is necessary, identifying potential challenges in recovering from a breakup is vital to properly planning to overcome the pandemic challenges (Huber et al., 2019; Li & Zobel, 2020).

Companies face many challenges in formulating SC recovery strategies. Resource limits are one of the challenges, especially for small and medium-sized companies. Efficient allocation of scarce resources is essential as companies struggle to decide on investment priorities for rapid recovery. Major disturbances in SC also affect broader socio-economic factors and the purchasing power of consumers (Huber et al., 2019). As a result of SC disruptions, companies have challenges at various levels of their operations, pointing to the prominence of the bullwhip effect. The bullwhip effect further reduces SC resilience and the ability to design and implement a recovery strategy (Li & Zobel, 2020). Recovery from disruption requires the formulation of flexible recovery strategies that take into account different scenarios and challenges (Wang & Yu, 2020). Flexibility is necessary because the effects of the pandemic-induced disorders on SC will vary. Therefore, different combinations of recovery strategies need to be considered, which is a common challenge for many companies. Recovery strategies to return to normal or better operational conditions after catastrophic events are vital for the rapid recovery and survival of SC. The conclusion is that the goal of the SCRM process is to limit the effects of SC disturbances that interfere with the continuity of material and information flows within the SC.

3. RISKS IN SC DURING THE COVID-19 CRISIS

Natural disasters, such as the COVID-19 pandemic, represent a special case of SCR in terms of duration (long-term), high uncertainty of consequences, and effects of spread. Disorders of SC caused by pandemics can threaten the resilience and reliability of SC, as shown in several studies (research by Kumar & Chandra (2010) on the impact of bird flu on US companies). The outbreak of the COVID-19 pandemic has affected the operations of global SCs by causing disruptions. The effects of the COVID-19 disruption have affected the global economy and temporarily stopped many industries. Statistics show that more than 94% of the largest companies have been negatively affected by this pandemic. Additionally, COVID-19 directly causes supply and demand disruptions at the global and local levels (Ivanov, 2020; Chowdhury et al., 2019). The field of SCRM is very broad and the need to control the negative impacts that inevitably occur is great. Therefore, the authors gave several definitions and categorizations of disorders that lead to adverse events. According to some studies, there are three main types of SCRs (Ivanov, 2020; Chen et al., 2015; Kumar & Chandra, 2010):

1. Internal company risks: control risk and process risk
2. Company external risks or internal SCR: supply risk and demand risk
3. External SCR: risk to the environment

The following is a brief description of control, supply, and demand risks (Figure 2). Special attention is paid to these risks because the pandemic has drastically affected their nature.

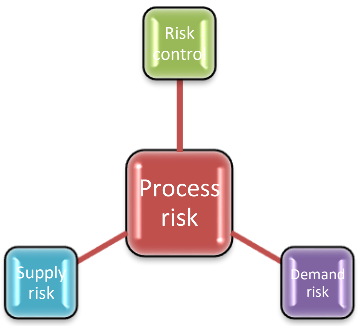

Figure 2. Types of SCR (Ivanov, 2020)

In the context of the pandemic business, the following is a short summary of control, supply, and demand risks. COVID-19 conditions have had a significant impact on the nature of these disturbances, so increased attention is being paid to them.

3.1 Supply risk

Supply risk includes all disturbances that occur between producers and suppliers. More precisely, this is related to the risk of delivery of raw materials of poor quality, at the wrong time, in the wrong quantity, etc. The consequences, such as delays in the production or delivery of finished products of poor quality, can lead to huge costs for the company during a pandemic. One of them was goods delivery stopped at the border due to the closure of countries in order to prevent the spread of the pandemic (Ali et al., 2019; Remko, 2020; El Baz & Ruel, 2021).

SC entities reported several different forms of supply disruptions and extended delivery times. Due to the stopped production in factories, the delivery time for certain products has been extended from day to week and from week to month. The company could have lasted during that period if there had been inventory, but there were major disruptions after that, resulting in the companies' inability to meet demand. Supply disruptions have occurred primarily due to the closure of some countries due to the pandemic. This prevented the uninterrupted supply of raw materials, semi-finished products, and finished products (Wijaya, 2021; Hosseini et al., 2019; Remko, 2020; Ivanov, 2021).

The effects of supply disruptions have led to delays in delivery when delivery requests increase again, i.e., return to the old level before the pandemic. This will have long-term consequences for the SC because the companies will need some time to return to "normal", i.e., to recover from the impact of the pandemic. The following discussion supports this. The factories resumed operations in China in 2020, but it took some time for them to reach full productivity again. The reason for this was partly because their supply sources were also exposed to disturbances, and they had to start working before the production volume increased. The implication of this is that, without changes in the design of the SC, supply disruptions due to COVID-19 will have long-term consequences after closure and quarantine if deals are done as they were before the pandemic (Remko, 2020).

In the period of the pandemic, there was a certain bottleneck in the implementation of logistics activities. Some deliveries can be transported by air, but this generates high costs. Reopening the plant will result in a high demand for transport capacity. The conclusion is that SC was not able to respond to supply disruptions. The insufficient applicability of the existing SC strategies for responding to emergencies caused by the COVID-19 pandemic must also be mentioned (Li & Zobel, 2020; Remko, 2020).

3.2 Demand risk

Demand risks are related to any type of disturbance in the flow of goods, information, or money. This risk often causes a discrepancy between the production plan and actual demand and occurs when demand significantly exceeds supply, or the other way around (Diabat, 2012).

According to SC management involved in reporting on the demand situation, there is an increase in demand for certain products, while others are facing a rapid decline. While demand for food, beverages, and necessities increased by 50% in 2020, demand for clothing decreased by 20%. Also, demand in the automotive industry has decreased significantly. The reason for that is the closure of factories at the beginning of the pandemic and the loss of jobs of many employees (Wang & Yu, 2020; Remko, 2020).

For example, in March 2020, there was a significant increase in demand for transportation services. Fear of people due to the outbreak of the pandemic relates to the need to order all the necessities on time. Some changes in demand are causing changes in ways and delivery methods, and they are stimulating a greater focus on digitization and visibility. The pandemic has led to a huge shift towards digital delivery, e-commerce, and online shopping services. Because they have invested a lot of money and energy in building e-businesses to survive during the epidemic, many corporations expect to keep their online enterprises even after the pandemic is over (Son et al., 2013; Wang & Yu, 2020; Remko, 2020).

3.3 Control risk

This risk category consists of the external risks to SC, which refers to all disturbances in the environment. These negative events can be the cause of economic, socio-political, or market changes and can both directly and indirectly affect the company. This type of event is very difficult to predict and control because it takes place in the very environment of the company, over which it has no influence. It is very important to emphasize that all these disorders are interconnected, and most often the occurrence of one risk causes another, which complicates the problem of SCRM even more (Son et al., 2013; Chowdhury et al., 2019, Lai et al., 2009).

The COVID-19 pandemic had a special impact on this segment, primarily during the introduction of various measures to prevent the spread of the infection. The measures that have contributed to the development of these risks are the ban on crossing borders, i.e., the locking of countries. This led to delays and non-realization of deliveries, which generated large costs for companies. It has also caused a large drop in good demand and declining revenues (Ali et al., 2019; Remko, 2020).

4. SUPPLY CHAIN RISK MANAGEMENT – SIGNIFICANCE IN COVID 19

Different industry trends, such as pronounced outsourcing, supply base reduction, just-in-time delivery, and shorter product life cycles, increased SCR exposure. The causes of risk in SC are different, and some of the key ones are related to human factors, information technology, natural disasters, etc. Within the available SC literature, SCRM has become a key area of interest (Fan & Stevenson, 2018). SCRM is a relatively complex process, as it involves understanding the risks and applying appropriate methods to reduce the consequences of their realization. In addition, it should be borne in mind that the consequences of risk can be intangible (reputation, credibility, authority). The risks in one part of the SC affect all its entities, which further complicates the SCRM process. Although much analysis has been done on SCRM, there are still areas that need further study (Fan & Stevenson, 2018; Remko, 2020).

Risk management in the SC has become particularly significant in the COVID-19 pandemic era. Due to the global disruption, SC has become significantly more vulnerable and sensitive at all levels. SCRM has never appeared more important than it is today when global SC has been heavily punched by the COVID-19 pandemic. One of the key questions is (Yang et al., 2021)?

According to El-Baz &Ruel (2021) and Ivanov (2021), the resource-based view and organizational information processing theory have a high impact on mitigating the role of SCRM practices during and after the COVID-19 pandemic. SCRM aims to reduce SC vulnerabilities. Previous SCRM studies have discussed various risk management strategies. Some of them include strategies for risk management within the company (investing in inventories, increasing flexibility, risk management culture), supplier management (supplier sustainability, flexible sources, alternative suppliers), and demand management (dynamic pricing, multiple modes of transport), etc. (Yang et al., 2021; El Baz & Ruel, 2021).

There are generally three steps in SCRM: identification, analysis, and treatment, i.e., risk response. Risk identification is the result of forming a list of all risks or only key ones. In this step, various qualitative and/or quantitative methods are used, and some of them are the checklist, interviews and group meetings, the Delphi method, what-if analysis, the Ishikawa diagram, etc. Risk analysis is performed from the aspect of impact on SC project management, i.e., analysis of the magnitude of consequences if the risk event is realized. Since the risk response is directly related to the type and magnitude of risk consequences, different risk treatments are present in SCRM. Five basic risk treatments stand out in the literature: acceptance, sharing, risk avoidance, transfer, and mitigation (Ivanov, 2020; Diabat et al., 2012).

4.1 Risk acceptance

Many companies agree to do business with risks. This does not mean that risks should be ignored. There are also clear principles on which risks a company should accept. A company should continue to monitor risks to ensure that accepted consequences do not escalate. If the consequences of a risk exceed a certain threshold, companies should consider how to avoid, transfer, share, or mitigate the risk. In the context of the post-COVID-19 pandemic, risk acceptance cannot be avoided. Each entity in the SC is faced with the fact that it is exposed to certain risks, so it undertakes certain activities in advance to limit the consequences (Son et al., 2013; Chen et al., 2015; Diabat et al., 2012).

4.2 Risk sharing

Risk sharing involves entities sharing some or all of the risks. It is known that the risk of one entity in the SC affects all others. Therefore, risk-sharing means sharing the consequences. Risk-sharing seems appropriate for dealing with risks that have a low probability and high impact to reduce the associated costs and increase customer service levels. In the context of a post-COVID-19 pandemic, the risks are shared to ensure fast and efficient customer service, but also to ensure continuous functioning in the SC (Diabat et al., 2012; Lai et al., 2009).

4.3 Risk avoidance

Risk avoidance is the attempt to eliminate the types of events that could result in a risk. If supply is unreliable, the company could discontinue flows of specific products, suppliers' activities, or the functioning of a geographic market if supply is unreliable, thus eliminating the root cause of the risk. In post-COVID-19 conditions, risk avoidance can mean removing a company from volatile markets. However, as the new conditions indicate that all entities in the SC are exposed to risk, avoiding the risk may also mean a break in the SC, which may result in the temporary closure of some companies (Diabat et al., 2012; Lai et al., 2009).

4.4 Risk transfer

Risk transfer implies that all responsibility is on “the other side”. The risk is transferred to the more resilient entity so that the consequences are fewer, which has a positive impact on the entire SC. In the context of the current pandemic, there are no clear guidelines for transferring risk. In this case, if the risk cannot be avoided, then it is transferred to the strongest link in the SC, i.e., to the entity that is currently most resistant to risk (Ivanov, 2020; Son et al., 2013; Lai et al., 2009).

4.5 Risk mitigation

Risk mitigation means taking all measures and actions to limit and/or possibly eliminate the consequences. It applies both to the reduction of the probability of a risk event and its consequences. Companies in the SC should consider sharing, accepting risk avoidance, and selecting appropriate risk mitigation strategies. The choice of a risk reduction strategy also depends on the type of risk and the company's budget. As risks are often interrelated, mitigating one risk can worsen or mitigate the others. In post-COVID-19 conditions, any risk-mitigating response is acceptable, provided that it does not endanger other entities and activities in the SC, especially not customer service (Chowdhury et al., 2019; Ali et al., 2019; Lai et al., 2009).

5. CONCLUSION

Supply chain risk management is a complex process because SCs generally function globally. Production may be in one nation, but product consumption may be in another, including reverse logistical flows that come from developed economies. In the SCRM, the pandemic has prompted new methods. Some initiatives to inhibit the virus's transmission have resulted in the identification of disasters or disturbances connected with the placement and use of specific goods. Changes in user behavior have been strongly influenced by current circumstances. Consumer behavior and purchasing power have been significantly influenced by measures adopted to curb COVID-19 transmission. As a result, businesses have struggled due to lower turnover as a result of lower customer demand. Furthermore, the COVID-19 challenges have an impact on all product prices, with a focus on fossil fuels as a promising future propulsion (Hosseini et al., 2019; Li & Zobel, 2020).

Due to the increasing importance of outbreak risks to the entire SC in COVID-19 conditions, this paper discussed commonly utilized proactive and reactive strategies that are utilized in practice that aim to limit the consequences of their realization. These techniques have a direct impact on increasing SC flexibility, which was a significant trump card for SC during the pandemic. It is important to note that there is still a scarcity of research on SCR. Previous research on SCR has been focused on the study of SC food, medication, and consumer items. It was concluded that there is a paucity of risk analysis and the design of treatment strategies in SC related to the COVID-19 impact on customer satisfaction. Only a small portion of the SCRM issues in pandemic situations were examined in this paper. The paper highlights some of the SCRM techniques, such as risk acceptance, sharing, risk avoidance, and mitigation, due to the complexity and longevity of SCRM. The study analyzes important risks faced by companies during the pandemic, such as supply and demand and control concerns. The above-mentioned pandemic risks can negatively impact the SC's resilience and hinder its recovery. SC recovery is necessary for SCRM and SC's long-term viability, so future research in this area will only become more attractive.

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LOGISTICS PROCESS OPTIMIZATION THROUGH DIGITALIZATION USING PROCESS APPROACH

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Abstract: *Companies must invest in quality - whether in the quality of services, products, processes, or the way of doing business. Hence the goal that all companies should strive for: to produce quality products or services, which enable the maximum fulfillment of customers' needs and requirements. The ability to achieve this, however, lies in the company's processes optimization. With process approach, control over processes is enabled and it can be used for their optimization. A case study of a selected boutique production company's processes was perpetrated. Based on existing process approach snapshot and review of current state of operations digitalization in the company, critical analysis was carried out. For the intention of improving business and competitiveness, we introduced an improved process approach based on ISO 9001:2015 standard. For the purposes of this paper, we will present the current state of one process and its proposed optimization through digitalization.*

Keywords*: logistics processes, process approach, operations planning, business optimization.*

1. INTRODUCTION

Optimized supply chain is very important for smooth business operations, for meeting the requirements and exceeding expectations of the company's customers. If the company's supply chain is managed properly, it can lower costs and accelerate production cycle. However, in the event of inefficient supply chain management, the company may risk losing customers or customers number reduction and consequently losing its competitive advantage within the industry (Grimshaw, 2020).

The supply chain includes: "life cycle processes that include physical, informational, financial and knowledge flows designed to meet the end users' needs with the products and services of several related suppliers" (Ayers, 2001). According to this definition, the supply chain includes those processes that cover a wide range of activities, including the supply, production, transport and sale of physical products and services, whereas life cycle refers to both the market life cycle and the life cycle of use (Ayers, 2001).

In connection with the supply chain, we must also mention logistics. There are many ways to define logistics, as Christopher (2005) provides a definition of the logistics basic concept: “Logistics is the process of strategically managing the procurement, movement and storage of materials, parts, and final inventory (and related information flows) through a company and its marketing channels in such a way that current and future profitability is maximized through efficient order fulfillment.” Logistics is a planning orientation and framework that seeks to create a unified plan for the flow of products and information through business. Supply chain management is based on this framework and seeks to link and coordinate the other stakeholders’ processes in the channel - customer suppliers and the company itself. Thus, for example, one of the supply chain management objectives could be to reduce or eliminate the buffer stocks that exist between companies in the chain by exchanging information on demand and current stock levels. (Christopher, 2005)

Due to the volume of work in companies, it is very important that we try to optimize internal processes as much as possible. Such optimization enables the company to produce products more efficiently, which will reach customers in a timely manner at lower costs. However, since logistics takes place everywhere, it is correct to present a few types of logistics, that are divided into five types by field (Logistics Glossary, b. d.):

- Procurement logistics, which manages raw materials and parts flow.
- Production logistics, which manages material flow within the company.
- Sales logistics, which manages products flow from manufacturer to customer.
- Recovery logistics, which manages customers return flow and waste returns.
- Recycling logistics, which manages recyclable materials flow.

Procurement logistics refers to the movement of goods when the raw materials and parts needed for production are supplied by suppliers. Many companies are actively involved in production, so that in appropriate times they procure the necessary materials in only the necessary quantities, because it is directly related to reducing the inventory costs. (Logistics Glossary, b. d.) As seen, the procurement function is a logistic function, which is immediately associated with supplies. In-depth studies reveal that its consequences are well beyond just supplies, and that the procurement logistics influences the whole logistic and supply chain. The procurement function can be defined “as the logistic function that handles the management of materials, equipment, spares, and services which must be received by the company, in the demanded conditions for the latter to perform its operations in an adequate manner, with the final objective of delivering the services required by its customers”. (Hernández & García, 2006) Successful supply chain management and quality operations are thus essential for the competitiveness of any company, and the first step to achieve this is the effective management of the company's internal processes, especially procurement process.

A process can be defined as “a set of interconnected or interacting activities that convert inputs into outputs”, with activities requiring the necessary resources allocation (ISO 9000:2008). The generic process consists of defined input requirements that amongst other include resources and raw materials. These are interconnected through various activities and control methods, which then provide the met output requirements or the process result (ISO 9000:2008). The outputs of one process are often the inputs of other processes and are interconnected throughout the system (ISO 9001:2015). Inputs and intended outputs can be tangible (for example: materials or components) or intangible (for example: energy or information). As a result of the procedure, in addition to the intentional product, unintended consequences may occur (for example: waste or pollution). Each process has customers and other stakeholders (which can be internal or external to the company), with needs and expectations that, based on the latter, define the required process results. (ISO 9000:2008). Each process also has specific control and measurement control points (CP) that are necessary for management and vary according to the risks associated with the process (ISO 9001:2015).

The ISO 9001:2015 standard is based on seven quality management principles: customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision making and relationship management. Based on the standard, a process approach can be defined as "the use of the system of processes in the company, together with the identification and interaction of these processes and their management to achieve the desired result" (ISO 9001:2015). The process approach helps the company plan its processes and their interaction. The ISO 9001:2015 standard encourages the adoption of process approach in developing, implementing, and improving the performance of the quality management system to increase customer satisfaction by meeting customer requirements. Understanding and managing interrelated and interconnected processes as a system contributes to the company's success and efficiency in achieving the intended results. The approach helps with management of the processes' interconnections and interdependencies in the system so that the overall effects of the company's operations can be improved.

The process approach includes systematic identification and management of processes and their interactions, which is why one of the process approach objectives is to help plan processes to achieve the intended results in accordance with the company's quality policy and strategic direction. (ISO 9001:2015) The use of process approach in a quality management system thus allows: understanding of requirements and their consistent fulfillment, addressing processes in terms of added value, achieving successful process implementation, and improving processes based on data and information evaluation. Therefore, the company must establish, document, implement and maintain a quality management system and continuously improve its efficiency in accordance with the requirements of ISO 9001:2015. Thus, the company must (ISO 9000:2008):

- Identify the necessary processes and their use for quality management system.
- Determine the sequence and interaction of the processes.
- Determine the necessary criteria and methods to ensure the effectiveness of operation and control of the processes.
- Ensure resources and information availability to support process management.
- Monitor, measure (where appropriate) and analyze the processes.
- Implement the necessary measures to achieve results and improve the processes.

Based on the above, each company must determine the number and type of processes required to meet its business objectives. The number and type of processes vary from company to company, but typical processes can still be identified as: business management processes; resource management processes; realization processes; and measurement, analysis, and improvement processes (ISO 9000:2008). The procurement can be found in two of the typical division processes: resource management processes and measurement, analysis, and improvement processes. The first include all the processes necessary to provide the resources needed to achieve the company's quality objectives and set results. And the latter include measurement, monitoring, auditing, performance analysis and improvement processes. Measurement processes are often documented as an integral part of process, resource, and implementation management.

Within the production company, as part of the types of logistics by fields, we know various business processes that may differ from company to company, but the basic business processes are in principle: procurement process, stock or inventory process, production process, sales and marketing process, the administration process and in general, and accounting and finance process. The procurement process is a business process related to the procurement of materials, raw materials, spare parts, goods, components, and other needs that are the foundation of the company's business. This process requires perfection, efficiency, and effectiveness in selecting all the listed elements. (KNIC, 2019) The process of stock or inventory control is a business process that regulates the entry and exit of elements such as materials, raw materials, semi-finished products, and the key is to control the flow of these elements (KNIC, 2019). Inventories are extremely important for enabling the continuous operation of all manufacturing companies. All companies operating through inventories have a large financial investment in the latter (Rusjan, 1999), as material costs can represent about from 20% to 60% of total production costs (Wilting & Hanemaaijer, 2014), thus each head of company or operations must devote a lot of time and attention to the procurement process. The good side of inventories is that they enable shortened products delivery times, reduction of congestion in the production process and risks reduction related to delays in delivery and incorrect forecast of demand. (Rusjan, 1999).

Procurement appears in various literature: as types of logistics by fields (procurement logistics), as typical processes (resource management processes) or as business processes within the production company (procurement process and stock or inventory process), which only confirms the importance of procurement. In each case, the interpretation of procurement is various and differ, but the essential components are the same everywhere, whether it is part of a process or a type.

2. METHODOLOGY

The research began with the current state of the studied boutique manufacturing company of plexiglass products. We divided the current state into a snapshot, which covers all company's' fundamental processes; a critical analysis, which we performed based on the snapshot and an interview with an employee. The snapshot of the current state primarily enables obtaining an objective picture of company's operations, based on which we get to know the actual business situation, which enables the creation of optimal plan and structure and operations organization of the company. The snapshot thus includes:

- Identification of critical points, their causes, and consequences.
- Obtaining basic decision-making information.
- A quick search for potential solutions that can be implemented immediately.
- Elimination of redundant or unnecessary activities.

This paper studies only company's fundamental processes, thus it was limited to the internal company's processes. Researching external company's processes would require the cooperation of business partners, stakeholders, and customers, which represents a more complex acquisition and processing of data.

The snapshot is presented as flowchart, that shows the selected process execution using the flowchart widgets, which are graphic symbols. The latter are describing: the beginning or end; an activity, process, or sequence of activities; decision or CP; and direction of activities or processes implementation order. With the selected charting software, a custom legend was created to facilitate the flowcharts understanding, showing the used symbols and their meanings. The following symbols were used:

- An ellipse, indicating the process beginning and end.
- An arrow, indicating the entry or exit into or out of the activity or process.
- A rectangle, indicating the activity or process taking place.
- A rhombus, indicating the CP where decisions are made.

The existing procurement process flowchart is well understood and fairly simple – it covers all important activities and clearly indicates the interaction between them, which makes it well-designed. Critical analysis of the procurement process is presented on an overview basis of individual activities, employee's interviews, and cooperation with the CEO, which has been obtained during the snapshot performance. Critical analysis provides insight into individual internal procurement activities and reveals potential problems and obstacles within the process. The primary purpose of critical analysis is to determine how the procurement process can be optimized through digitalization.

An integral part of the company's existing process approach is the large number of simple as well as complex processes within which various activities take place. Thus, the current process approach has been divided into five fundamental processes. The first fundamental process of studied company, that crucially underpin the company's business, is procurement. The latter is a basic condition for starting a manufacturing company, as it includes activities such as inspection and inventory review, review of suppliers and selection of suitable partners, ordering new and necessary materials, checking the quantity and quality of supplied materials, and much more. Due to the importance of procurement, we decided to analyze the selected company's procurement process, which is the foundation of any production company. The remaining fundamental processes were demand and supply; custom product production; retail product production; product handover and sale. In the following chapter, an overview and a diagram of current procurement process will be presented with all its activities.

3. RESULTS AND ANALYSIS

As already mentioned, procurement is of key importance for manufacturing company's operation and is also the first process that begins to take place in this studied process approach. The following sub-chapter describes the current procurement process and its critical analysis. A renewed, improved procurement process is then presented as proposed solution of optimized process through digitalization.

3.1 Current procurement process and critical analysis

Figure 1 shows procurement process, which begins with an inspection of warehouse stock of materials, which requires a blank document with a table for the materials inventory, which was created by the CEO. An employee reviews and counts the material in stock and writes it in the table. The completed table represents the starting point for the necessary material orders, as it shows material shortage. The employee then hands over the completed table to the CEO, who reviews the suppliers' offers for the necessary materials, based on the table, and selects the appropriate one. The latter is sent the necessary material order, for which the order confirmation by supplier is needed. The waiting period for the ordered material delivery begins. When the supplier delivers the ordered material, an employee must first check the purchase order issued by the CEO. It states the material type, its quantity and price. This is followed by checking the material – whether the material type, quantity, quality, and price are correct. It has already happened that the supplier delivered the wrong material or that one ordered material type was not delivered. In this case, the reviewing employee must immediately notify the CEO and report the defect to the supplier. The material ordering activities are then repeated – if all the material has arrived and met the criteria (material type, quantity, quality, and price), the reviewing employee must sign the delivery note and accept the invoice from the supplier. The invoice is then submitted to the CEO, who forwards it to the accounting department for payment transfer. The material is then transferred to warehouse room, where it awaits production.

From the sole beginning, it was possible to observe the long-term and redundant activity, where employees inspect material warehouse stocks on hand. The employee needs a warehouse inventory table, which must be completed whilst inspecting the material stocks and upon completion delivered to the CEO. This activity is ineffective since a lot of valuable time could be used more optimally. Overall, the company takes the procurement process very seriously. They are aware that without good procurement they cannot maintain a competitive position in the market, so they spend a lot of time reviewing the supply market for plexiglass material. Although the company does business with a few regular suppliers, they are constantly reviewing other suppliers offers. In the past, one of the regular suppliers had higher prices of plexiglass material than the others – one might think it was because of better material quality. After the comparison, a conclusion was made that both suppliers have the same quality material, except that the permanent supplier raised prices due to the higher demand caused by the COVID-19 pandemic. Thus, the company changed one of its permanent suppliers, by which they reduced purchasing costs and maintained the same quality.

Delivered material on request is inspected every time it is received. If damaged panels of plexiglass material arrive, they will be rejected, and new ones are ordered immediately. In this case, the cost of damaged material is paid by the supplier, and the delivery time of new material is shorter since the error was made on the supplier’s side. The same procedure occurs in the case of wrong material delivery or forgotten delivery of a specific material type. As described, an employee must sign the delivery note upon material receipt – if the material was not suitable, the delivery note is not signed. After material receipt, the latter is transported to the warehouse room of the company's premises, where the material stand is installed. The stand has sorted drawers for different plexiglass material types, which differ in thickness and color. The company does not own a large storage facility, which could be a big advantage.

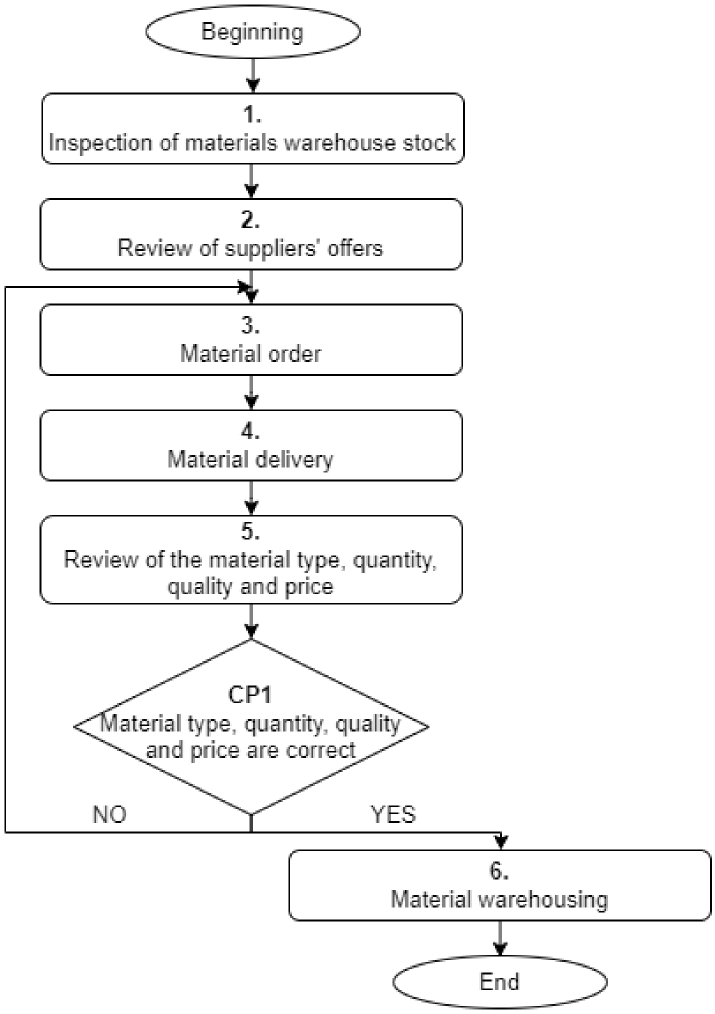

Figure 1. Current procurement process flowchart

3.2 Proposed solution of optimized procurement process through digitalization

An improved and optimized procurement process flowchart eliminates ineffective and redundant activities whilst including optimized activities, which would help whit efficiency of company's business. The procurement process may seem more complex and extensive, but it includes basic procedures to improve the process.

Proposed optimized procurement process is shown in Figure 2 and begins in the same way as the current process – with an overview of material stocks. For the first activity (inspection of materials warehouse stock), employees no longer need a document with inventory table, as the first improvement would be the implementation of material recording by a computer system. The procedure would take place when the material is taken directly from the warehouse and / or by issuing an invoice to the customer. As part of this improvement, the implementation of a computerized invoicing system is suggested, which would record the amount of plexiglass material used for a product. The amount of produced waste material would also be recorded in the program – this would not be visible on the customer's invoice. Currently, the company is issuing delivers notes upon products receipt by customers. Such recording would update the material stocks quantity on an ongoing basis, which eliminates the need to manually review materials stock, enables real-time data and employees time optimization.

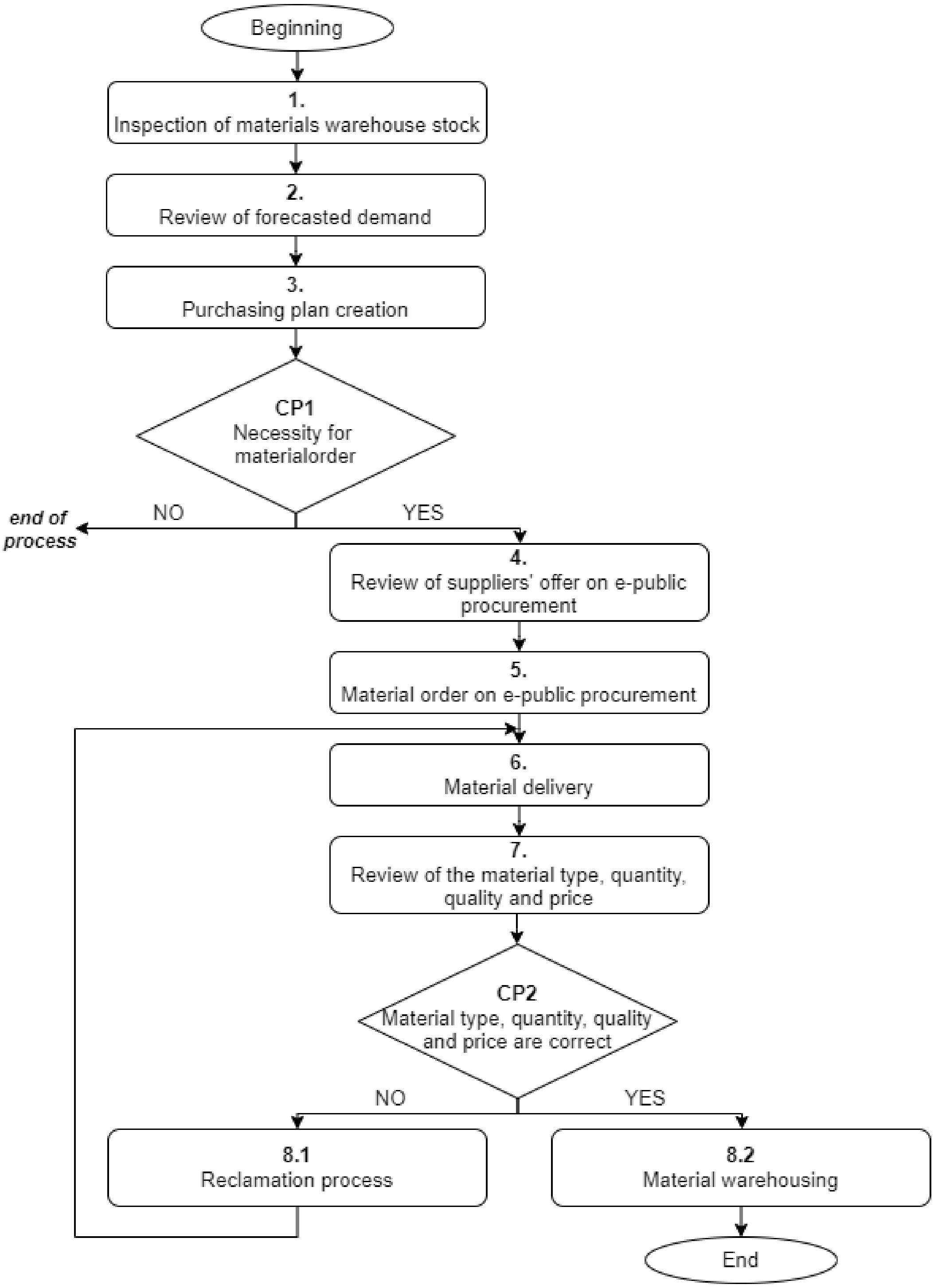

Figure 2. Proposed procurement process flowchart

Computerized invoicing system implementation would save space used to store delivery notes, annihilate search time for old invoices and stock inspection (since it would already be in the system). The system would also increase company's transparency and reduce environmental impact of paper consumption. For system's optimized use, it is recommended to purchase at least one tablet which would prevent running around the company's premises, as employees cannot carry around stationary computers. Thus, all the necessary data would be at the grasp of hand and entered directly into the system through the tablet, which should support such a system.

Next proposed solution would be the implementation of the Kanban system, which manages lean Just-in-Time production. It was developed to improve production efficiency through the main advantage of the system – setting a permissible stock limit to avoid low or high stock levels (Wallace & Spearman, 2004). The CEO would specify and determine the allowed minimum and maximum materials stock limit as, for example, for transparent plexiglass material at 40% (this material type is used on daily basis), and for non-regular plexiglass material at 10%. When the stock of transparent plexiglass material would reach 40% or less, the system itself would report a shortage through the computer system. An upgrade would be for the system to communicate the material shortage directly to the supplier, which saves time in placing the order.

As third proposed improvement, but primarily necessary, demand forecasting was suggested. The demand forecast can be calculated based on past sales data. An example of such calculations model is ARIMA, which allows various settings based on the company's needs. The most up-to-date information for future demand can be obtained from large amounts of data. The more values entered, the more accurate the calculation will be – data for consecutive years, where monthly, weekly, or daily data are entered. Thus, the company would avoid in-bulk purchases and the material shortage challenges.

In case of non-implementation of material recording computer system, the materials stock reviewing and demand forecasting would be assigned to the CEO, who regulates the necessary materials purchase. Despite the non-implementation of the computer system, implementation of demand forecasting is strongly recommended. Obtained past sales data represent the foundation to prepare and create a purchasing plan, which is one of the most important parts of the company's business plan. The latter specifies the exact material requirement quantities, the calculation of orders number and their cost. At this point, the CEO decides whether a material order is necessary. If not, the procurement process ends here. In the case of an affirmative answer, a review of suppliers' offer on e-public procurement website follows. This activity is not imperative with every order, but it is recommended to execute it every few months, since it checks various suppliers offers, which change with time. The use of e-public procurement or e-purchasing is similar process to using consumer goods (Collins, 2012). It starts with browsing the suppliers' websites of the selected material. The comparison and purchase website can be visited to compare prices. The company's material requirements are specified to suppliers on the website, and the process ends with a transaction via electronic payment. This option provides the benefits for managers by helping them communicate with suppliers and potential suppliers, reducing the time of e-mails, costs of purchased goods, and the administrative costs associated with transactions. The process is faster and at the same time encourages better communication.

After the order is placed, the delivery waiting period begins. Upon delivery, the material is inspected as before (or with the help of material recording computer system). If the wrong materials have been delivered, the activity continues in the reclamation process – the CEO and the supplier are informed of the error and re-delivery is needed. If all the material is suitable, the delivery note is signed, the invoice is accepted, and the material is warehoused until use.

4. CONCLUSION

Up-to-date and detailed procurement planning enables inventory and procurement costs reduction with efficient production process. Thus, through optimized procurement planning, it is possible to coordinate purchasing activities with production. The main advantage of process approach, compared to others, is in the processes and activities' management and interactions control. For the most possible business optimization, it is necessary to harmonize all processes with the company's objectives, scope, complexity, and design them to add value. Using a process approach can improve a company's performance. Processes are managed as a system defined by a network of processes and their interactions, which creates a better understanding and transparency of the entire system, which allows its optimization and consequent increase in added value.

Every company has the need to be competitive in the business market, especially today, when facing the consequences of the COVID-19 pandemic. For this purpose, the current procurement process of the selected company was reviewed. Based on the latter, a proposed solution of optimized procurement process was made through digitalization. Despite the increased workload, the company has implemented demand forecasting this year, which allows yearly finance planning, that has been divided into materials, equipment, machinery, employees and other. Although the optimized procurement process has not been fully implemented, the partial implementation has made it possible to plan financial investments into new employment, purchase of a tablet and machinery.

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LOGISTICS 4.0 IN THE FUNCTION OF CIRCULAR ECONOMY IN THE AGRI-FOOD SECTOR

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Abstract: *By applying the solutions and technologies of Industry 4.0 in the field of logistics, the concept of Logistics 4.0 was developed. On the other hand Circular Economy (CE) is a model of production and consumption that ensures sustainable growth over time. The subject of this paper is to rank the main Logistics 4.0 based CE interest areas within the agri-food sector. The aim is to determine the areas which has the greatest potential for further development and should thus be in focus of the future planning. This is a multi-criteria decision making (MCDM) problem. For solving it a hybrid MCDM model combining the Analytical Hierarchy Proces (AHP) method for establishing the criteria weights, and the Comprehensive distance-Based RAnking (COBRA) method for the final ranking of the alternatives, is proposed. The results indicate that the most important CE interest areas are Reuse/Remanufacturing/Recycle, Supply Chain Management and Product Lifecycle Management.*

Keywords*: Logistics, Industry 4.0, Circular economy, Agri-food, MCDM, AHP, COBRA.*

1. INTRODUCTION

In the broadest sense, logistics encompasses all systems and processes that enable the movement of material and non-material flows (Zečević, 2006). Processes that include the movement of these flows can be grouped from the aspect of direction and identified with the terms of forward logistics (flows from the place of origin to the place of consumption) and reverse logistics (flows from the place of consumption to the place of disposal, destruction, reuse, remanufacturing, recycling, etc.). However, both are covered by the term closed loop supply chain (CLSP) (Kumar & Kumar, 2013), which is often identified with the circular economy (CE) concept (Farooque et al., 2019).

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The main goals of the CE are the optimization of resources, reduction of raw materials consumption, and waste recovery by recycling or giving a product or some of its parts a second life. Therefore, CE is seen as a new production and consumption model that ensures sustainable growth over time. Hawing in mind the increasing importance of sustainability, it is clear why CE is becoming an important research topic, and especially the optimization of logistics processes that enable its efficient functioning. A significant contribution to the optimization of these processes is made by modern technologies developed within the paradigms known as Industry 4.0 (I4.0). The application of these technologies and their mutual networking for the realization of logistics activities has led to the creation of the concept of Logistics 4.0.

I4.0 represents a revolution that has initiated significant changes in all areas of human activity, including the agri-food sector as one of the primary, if not the most important economic sectors. Since it is fundamental to face the challenge of food security in the coming years, the agri-food sector cannot allow itself to lose the opportunities offered by modern trends brought by the concepts of CE and Logistics 4.0. Accordingly, the aim of this paper is to consider the possibilities of applying I4.0 technologies for the implementation of logistics activities in the CE interest areas within the agri-food sector and to rank these Logistics 4.0 based CE interest areas in order to identify those which have the greatest potential for further development and should thus be in the focus of future planning and development of strategies. Since this is a multi-criteria decision-making (MCDM) problem, a hybrid model which combines Analytical Hierarchy Process (AHP) method and the Comprehensive distance-Based RAnking (COBRA) method is proposed for solving it.

The paper is organized as follows. The next section deals with the establishment of the Logistics 4.0 based CE interest areas in the agri-food sector. The third section provides the methodology for prioritizing the CE interest areas, while the following section provides the obtained results. Final section provides main conclusions.

2. LOGISTICS 4.0 BASED CIRCULAR ECONOMY IN THE AGRI-FOOD SECTOR

Logistics 4.0 is defined as the application of the I4.0 technologies in logistics (Krstić et al., 2021). I4.0 technologies that found the widest application in logistics so far are Internet of Things (IoT), Autonomous Vehicles (AV), Automated Guided Vehicles (AGV), Artificial Intelligence (AI), Dig Data and Data Mining (BD&DM), Blockchain (BC), Cloud Computing (CC), Augmented Reality (AR), Additive Manufacturing (AM), Progressive Robotics (PR) and Electronic/Mobile Markeplace (EMM) (Krstić et al., 2021; 2022).

The CE is "*a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible, thus extending the life cycle of products*" (EP, 2021). CE is mostly related to reverse logistics (e.g. Julianelli et al., 2020). However, if one carefully analyzes one of the main objectives of CE, which is to plan the product life cycle to minimize or avoid any waste in the first place (EMF, 2012), it is clear that CE encompasses the entire supply chain and that in addition to return logistics includes forward logistics. Rosa et al. (2020) identified supply chain management (SCM), circular business model (CBM), product lifecycle management (PLM), digital transformation (DT), resource efficiency (RE), smart services (SS), reuse (RU), remanufacturing (RM) and recycling (RC) as the main CE interest areas. CE is very much influenced by the new business paradigm brought by the development of I4.0

through the application of modern technologies in its main interest areas. Of course, this paradigm shift is present in all economic sectors, including the agri-food sector, which will be further investigated in the following.

2.1 Supply chain management

SCM as one of the broadest interest areas of CE provides most opportunities for the application of various I4.0 technologies for performing logistics activities. IoT is used in almost all phases of the agri-food supply chain and all logistics subsystems. It can be used for managing and processing orders, information between different participants in the chain, transport operations, vehicle fleet (locating, routing), warehousing operations, inventory levels, automatic packaging and labeling, smart packages that have the ability to monitor various parameters of goods, etc. AV could be applied as a replacement for retail facilities which would lead to a change in business and distribution models. AGV technology is widely used in various parts of the agri-food supply chain, primarily for the implementation of internal transport and transshipment processes in various nodes of the logistics network. AI-based systems in agri-food SCM contribute to maintaining the quality of agri-food products through testing and monitoring of food at each stage of the supply chain, enable sorting of products against a number of criteria in a short time, provide and improve hygiene standards by accelerating the sanitation of vehicles and equipment, enable the preparation of food and beverages according to the specific requirements of users, etc. The application of BD&DM technology facilitates SCM in the agri-food sector by supporting the management of various segments of the supply chain, such as order processing, transport, storage, inventories, packaging, available resources planning, last mile optimization, customer loyalty management, supply chain risk management, valorization of returns, etc. BC technology enables the creation of transparent, reliable, unchangeable and verifiable records that are the basis for the development of the agri-food traceability system. CC technology provides the flexibility needed to cope with the unpredictable variations in supply quality and quantity that characterize agri-food supply chains. CC enables more efficient application of various systems that are integral parts of SCM. AR technology can be used to improve the efficiency of agri-food product processing, product advertising, quality assessment, etc. AM technology supports personalized mechanisms for nutritional control and development of food products in accordance with the specific requirements of users. PR technology is used in agri-food supply chains in the stages of providing raw materials (for sowing crops, harvesting, etc.), in the production phase to perform various operations of processing, production, packaging, etc., as well as in the distribution stages to perform various storage operations (loading, unloading, sorting, etc.). EMM facilitates participants in the agri-food supply chains to procure, trade and cooperate with partners, diversify business opportunities, improve profitability and access the new markets that were previously inaccessible due to the geographical barriers.

2.2 Circular business model

In the agri-food sector, I4.0 technologies can be applied for the realization of numerous processes in the field of logistics. IoT can be applied to establish a flow control system based on Kanban management method to visualize the locations, times and quantities of goods and materials collection/delivery, which is especially important for the agri-food products that have a limited expiration date. IoT can also be used to collect large amounts of data, whose adequate structuring and analysis using BD&DM technologies can improve the overall circularity of the system. In addition, BD&DM can be used to establish strategic and tactical decision support systems, to plan agri-food logistics network by identifying locations for delivery and collection of agri-food products and ways to connect them, manage customer loyalty, as well as to assess innovative business models. AI can be applied to simulate the CE system with the aim of auditing cooperative agri-food networks, assessing the impact of changing business models, as well as to forecast the potential for redistribution of production. BC technology can enable better business cooperation between network participants by ensuring the security and confidentiality of data and information exchange, which is especially important for the logistics of agri-food sector whose flows are accompanied by a large number of documents. EMM has high potential in the agri-food sectors, especially in recent years in the circumstances of the COVID-19 pandemic. EMM enables the creation of new business models and logistics markets through supply expansion and services improvement.

2.3 Product lifecycle management

In the agri-food sector, various I4.0 technologies can support performance of forward and reverse logistics operations encompassed by the PLM as one of the interest areas of the CE. IoT can be applied for establishing a platform for animal/food product information sharing, track of raw materials and finished products, their surveillance during consumption in the consumers' households and undertaking the proactive corrective actions before the corruption of the products, e.g. food spoilage due to the inadequate storage, expiration, etc. AI in combination with other I4.0 technology can be applied to support various logistics-related operations in the agri-food sector. With the support of BD&DM technology for market analysis, identification of target users and their requirements, AI can be applied to agri-food product design, rapid concept development based on existing products, improving the quality of innovation and efficiency of product design, providing accurate, high quality and personalized services of sales, product deliveries, product returns and other related services, etc. In combination with AR technology, AI can be used for personalized and collaborative product design, especially packaging, that can have a crucial impact on the agri-food product attractiveness, testing and inspection, visualization and planning of warehousing operations, etc. BC technology can be applied for PLM in the agri-food sector to manage customer relationships and product data, quality, origin tracking, counterfeiting prevention, etc. CC facilitates the development of a PLM system that integrates various individual systems to control internal operations, as well as the creation of a cloud production system. AM strengthens PLM competencies by improving the performance of agri-food products, such as faster production, reduced product development costs, improved product quality, better material control, etc.

2.4 Digital transformation

Most of the technologies related to I4.0 have a significant impact on the DT in the agri-food sector through the implementation of various logistics activities. IoT enables digitalization of relations between participants in logistics chains through the establishment of systems for collecting, exchanging and managing information on various chain processes quickly and accurately in order to overcome problems arising from the great diversity of agri-food products and specific requirements for the logistics processes.

These systems have the ability to collect, monitor and analyze data in real time, thus creating databases that can be used in decision-making processes. CC technology enables wider and more efficient application of various systems, such as Enterprise Resource Planning (ERP), Electronic Data Interchange (EDI), telematics, etc., in the cloud. With the support of BD&DM technology, these systems support responsible business management, which enables the valorization of agri-food products, obtaining of timely warnings, anticipating the adverse situations, planning the actions to eliminate the consequences, etc. AI enables digitalization of monitoring the status of goods and means of transport, and with the support of AR technology facilitates the implementation of logistics activities, primarily those related to transport. EMMs are closely related to DT because they are the main drivers of digitalization of the market, which enables the realization of very fast electronic transactions, which is of particular importance in agri-food supply chains. As these electronic transactions are subject to abuse, the required level of security is provided by the BC technology, which enables the creation of digital contracts, digital bill of lading, etc. AM as a new production technology leads to the digitalization of food design and production processes thus enabling product characteristics to be adapted to individual requirements of consumers in relation to their health and physical activity. PR technology contributes to the digitalization of the process of storage/warehousing, sorting, internal transport and other activities which support the production process.

2.5 Resource efficiency

Logistics operations provide additional margins for achieving RE in the context of CE which by definition already implies resource saving and does not leave much room for further improvements. These improvements in the agri-food sector can be achieved by applying various I4.0 technologies. IoT can be used to develop a system that improves productivity based on the collection of data on the engagement of resources, both natural and other, in real time and making adequate decisions based on them. The system enables monitoring and identification of processes that are less efficient and suggests actions for their optimization. AVs, which often include electric drive, which automatically select and follow optimal routes and do not require the involvement of drivers, contribute to the reduction of natural resources, primarily fuel, but also other resources, primarily monetary, time and human. AI technology, supported by BD&DM technologies for data collection and analysis, can be used to identify potential places for resource rationalization, as well as resource savings through better planning of logistics operations, primarily transport and inventory, but also ordering and warehousing. Optimal planning of logistics operations reduces the consumption of energy and other resources through better allocation and capacity planning. BC technology provides savings in time and human resources through checking, controlling and ensuring the accuracy and reliability of information and data on transport documents, inventories status, customer requirements, providers and other participants in the chain. CC technology through sharing enables savings in the purchase and use of hardware and software resources used in all phases of the logistics chain, as well as the people needed to install and maintain them. Through the visualization of production and logistics operations, primarily transport, storage and transshipment, AR technology enables better preparation, planning and optimization of processes in the agri-food sector. AM enables the reduction of energy consumption, primarily fuel, due to the reduction of transport activities since the raw materials can be found closer to the place of production. Additionally supported by PR technology, AM also enables the reduction of manpower that has been replaced by machines, as well as costs and time of performing production and logistics processes, primarily transshipment and warehousing, but also AGV supported internal transport processes. EMM enables the allocation of resources, primarily monetary, time and human, which would initially be used for the implementation of traditional trade operations, to other activities, primarily logistics.

2.6 Smart services

In the agri-food sector, most I4.0 technologies are applied to the development of SS in all phases of the supply chain. IoT can be used for procurement of raw materials to provide crop performance assessment services. IoT can also be used to develop systems that identify shortages or expiration of certain agri-food products, and automatically initiate procurement and distribution or reverse logistics processes. Combined with CC and BC technologies, IoT enables the development of advanced product tracking services. CC in combination with EMM technology can be used to develop a smart online shopping platform that can provide essential information to both buyers and sellers that can ultimately lead to higher sales and higher profitability, improved marketing and pricing strategies, etc. Furthermore, EMM in combination with AR technology can be used to improve the experience of online retail shopping by providing potential customers not only to review the product to the smallest detail, but also to suggest modifications that can be implemented using AM technology (e.g. product or packaging customization, installation of various sensors, etc.). AV can be used for smart agriculture, for the processing like sowing, fertilizing and harvesting agricultural products, i.e. for the processes of providing raw materials in the supply chain. They can also be used in the phases of agri-food supply chains in charge of distributing and delivering products to the end users, as well as collecting and returning them in reverse logistics processes. AGV vehicles can replace the work of people in harsh environments that prevail in the nodes of agri-food supply chain networks that arise as a result of requirements for certain temperature regimes. In combination with PR and AI technologies, they can be used for automatic collection, sorting and packing of eggs, milking and feeding cows, automatic cleaning, reloading, transshipment, etc. In addition, BC technology enables reliable product traceability, which is especially important in the agri-food sector. BD&DM technology can be applied for forecasting, benchmarking and creating risk management models.

2.7 Reuse/Remanufacturing/Recycling

RU, RM and RC are the main processes that drive the return logistics activities. RU in the agri-food sector mostly refers to the redistribution of products in order to reduce the volume of surplus products generated. RM also referred to as the refurbishment or reconditioning, in the agri-food sector implies the return of the damaged or faulty packaged products, misshaped products, wrong weighted products, broken products, etc., with the aim of eliminating these shortcomings and re-producing the same products in accordance with the expected and designed characteristics. RC in the agri-food sector refers to the use of raw materials obtained from processing the returned or waste products to produce other products, such as animal food, biomasses for fertilization, energy sources (bio-fuels), etc. Almost all I4.0 technologies used in this interest area of CE are used in order to form a single waste and returnable management system consisting of four basic modules: collection, transport, redistribution, and processing. In the collection and redistribution modules, IoT technology can be used to communicate objects such as waste collection bins, vehicles and retail shops, which ensure efficient and fast waste collection, distribution, better utilization of vehicles, better route planning, etc. In this module, as well as in the transport module, there is a wide scope for application of the AV technology. With the support of BD&DM technologies, which collect, store and process large amounts of data, and AI technology, which allows automatic decision making, these vehicles reach their full potential and can completely independently perform processes of collection, distribution and transport. AGV technology can be used in the processing module to perform the internal transport process. Other technologies such as IoT, BD&DM, AI and PR are used in this module to implement the processes of sampling, classification, sorting, monitoring, as well as for data statistical analysis. AM technology through promoting in-situ recycling affects all three modules since it enables local sourcing, which simplifies collection processes, reduces transport distances and thus makes it cheaper, and combines processing with production activities. BC technology allows tracking of materials with unique codes or digital badges from the moment of collection to the moment of processing. With CC technology, the entire waste and return management system can function fully in the cloud, reducing the required hardware and software resources.

3. METHODOLOGY

To solve the MCDM problem in this paper, a hybrid model is defined that combines AHP (Saaty, 1980) and COBRA (Krstić et al., 2022) methods. The AHP method was used to obtain criteria weights, while the COBRA method was used to rank the alternatives. Application steps of the proposed hybrid MCDM model are described below.

First it is necessary to define the problem structure, i.e. the objective, alternatives and the criteria for their prioritization. Afterwards, it is necessary to define the evaluation scale for prioritization. This paper used the standardized nine-point Saaty scale in which 1 represents “Equal importance” and 9 represents “Extreme importance” (Saaty, 1980).

Application of the AHP method for obtaining the criteria weights begins with the establishment of pair wise comparison matrices:

$$P = \lfloor p_{ij} \rfloor_{oxo}, p_{ij} = 1, p_{ji} = 1/p_{ij}, p_{ij} \neq 0 \quad (1)$$

elements of which are p_{ij} *(i,j=1,2,...,o)* and denote the importance of element (criterion, sub-criterion) *i* in relation to element *j*. Afterwards, it is necessary to obtain the element weights based on the eigenvector. First, it is necessary to set up a matrix equation:

$$PW = \lambda_{\max} W \quad (2)$$

where *W* is the element weights matrix elements of which are w_i ($\sum_{i=1}^{o} w_i = 1$), and λ_{max} is the eigenvalue of the matrix *A*. In order to control the results of the method it is necessary to calculate the Consistency Ratio (*CR*) for each matrix and the overall inconsistency of the hierarchical structure. *CR* is calculated as (Saaty, 1980):

$$CR = CI / RI, \quad (3)$$

where *CI* denotes the Consistency Index and can be calculated as:

$$CI = \frac{\lambda_{\max} - o}{o - 1} \tag{4}$$

RI denotes the Random Index, *CR* is used for checking the consistency of pair wise comparisons and must be less than 0.10. Only then it can be said that the comparisons are acceptable.

For ranking the alternatives using the COBRA method (Krstić et al., 2022) it is necessary to form the decision matrix *A* by evaluating the alternatives in relation to criteria using the Saaty scale.

$$A = \lfloor a_{ij} \rfloor_{mxo} \tag{5}$$

where a_{ii} is the preference value of alternative *j* (*j=1,...,m*) in relation to criterion *i* (*i=1,...,o*). Afterwards it is necessary to obtain the normalized the decision matrix:

$$\Delta = \left[\alpha_{ij}\right]_{m \times o}, \ \alpha_{ij} = \frac{a_{ij}}{\max_j a_{ij}}, \tag{6}$$

as well as the weighted normalized decision matrix:

$$\Delta_w = \lfloor w_i \times \alpha_{ij} \rfloor_{m \times o}, \tag{7}$$

where w_i is the relative weight of criterion *i*.

For each criterion function it is necessary to determine the positive ideal (PIS_i), negative ideal (NIS_i) and average solution (AS_i) in the following way:

$$PIS_i = \max_j (w_i \times \alpha_{ij}), \forall i = 1,...,o \ for \ i \in B, \ PIS_i = \min_j (w_i \times \alpha_{ij}), \forall i = 1,...,o \ for \ i \in C \tag{8}$$

$$NIS_i = \min_j (w_i \times \alpha_{ij}), \forall i = 1,...,o \ for \ i \in B, \ NIS_i = \max_j (w_i \times \alpha_{ij}), \forall i = 1,...,o \ for \ i \in C, \tag{9}$$

$$AS_i = \frac{\sum_{j=1}^{m} (w_i \times \alpha_{ij})}{o}, \forall i = 1,...,o \ for \ i \in B, C, \tag{10}$$

where *B* is the set of benefit and *C* the set of cost criteria.

For each alternative it is necessary to determine the distances from the positive ideal ($d(PIS_i)$) and negative ideal ($d(NIS_i)$) solutions, as well as the positive ($d(AS_i^+)$) and negative ($d(AS_i^-)$) distances from the average solution in the following way:

$$d(S_i) = dE(S_i) + \sigma \times dE(S_i) \times dT(S_i), \forall i = 1,...,o \tag{11}$$

where S_i represents any solution (PIS_i, NIS_i or AS_i), σ is the correction coefficient obtained in the following way:

$$\sigma = \max_j dE(S_i)_j - \min_j dE(S_i)_j \tag{12}$$

$dE(S_i)_j$ and $dT(S_i)_j$ denote the Euclidian and Taxicab distances, respectively, which are for the positive/negative ideal solution obtained as follows:

$$dE(PIS/NIS_i)_j = \sqrt{\sum_{i=1}^{o} (PIS/NIS_i - w_i \times \alpha_{ij})^2}, \forall j = 1,...,m, \forall i = 1,...,o \tag{13}$$

$$dT(PIS / NIS_i)_j = \sum_{i=1}^{o} \left| PIS / NIS_i - w_i \times \alpha_{ij} \right|, \forall j = 1,...,m, \forall i = 1,...,o \tag{14}$$

and for the positive/negative distance from the average solution obtained as follows:

$$dE(AS_i)_j^{+/-} = \sqrt{\sum_{i=1}^{o} \tau^{+/-} (AS_i - w_i \times \alpha_{ij})^2}, \forall j = 1,...,m, \forall i = 1,...,o \tag{15}$$

$$dT(AS_i)_j^{+/-} = \sum_{i=1}^{o} \tau^{+/-} \left| NIS_i - w_i \times \alpha_{ij} \right|, \forall j = 1,...,m, \forall i = 1,...,o \tag{16}$$

where

$$\tau^{+} = \begin{cases} 1 \ if \ AS_i < w_i \times \alpha_{ij} \\ 0 \ if \ AS_i > w_i \times \alpha_{ij} \end{cases}, \tau^{-} = \begin{cases} 1 \ if \ AS_i > w_i \times \alpha_{ij} \\ 0 \ if \ AS_i < w_i \times \alpha_{ij} \end{cases} \tag{17}$$

Final ranking of the alternatives is established according to the increasing values of the comprehensive distances (dC_i) obtained in the following way:

$$dC_j = \frac{d(PIS_i)_j - d(NIS_i)_j - d(AS_i)_j^{+} + d(AS_i)_j^{-}}{4}, \forall j = 1,...,m \tag{18}$$

4. PRIORITIZING CE INTEREST AREAS IN THE AGRI-FOOD SECTOR

Prioritizing the CE interest areas is the MCDM problem which is solved by applying the established model. The first step of the model implies the definition of the problem structure (objective, alternatives, criteria and sub-criteria). The objective is clear, to identify the CE interest areas that contribute most to the sustainability of the CE system in the agri-food sector. Alternatives are thus the CE interest areas explained in section 3. The only elements remaining for the establishment of the problem structure are the criteria and sub-criteria for the evaluation of the CE interest areas.

Since CE is a systematic approach to economic development designed to benefit businesses, society, and the environment, three main criteria are defined: ***Economic*** (Ec.), ***Social*** (So.) and ***Environmental*** (En.). Economic criterion further includes sub-criteria: ***Implementation costs*** (Ec.1), ***Operational costs*** (Ec.2), and ***Material value preservation*** (Ec.3); social criterion includes: ***Health*** (So.1), ***Safety*** (So.2), and ***Labor market*** (So.3); and Environmental criterion includes: ***Waste reduction*** (En.1), ***Emissions reduction*** (En.2), and ***Energy resource preservation*** (En.3).

The following steps of the proposed model imply the establishment of the criteria and sub-criteria weights using the AHP method. The pair wise comparisons of the criteria and sub-criteria are established and pair wise matrices are obtained according to the equation (1). By applying the equation (2) the criteria and sub-criteria weights are obtained. Pair wise matrices and the obtained weights are presented in Table 1. By applying the equations (3) and (4) the consistencies of the evaluations are checked and all values were less than 0.1, which means that all comparisons are acceptable.

Table 1. Pair wise comparison of criteria/sub-criteria and obtained weights

	Criteria			Sub-criteria											
	Ec.	**So.**	**En.**		**Ec.1**	**Ec.2**	**Ec.3**		**So.1**	**So.2**	**So.3**		**En.1**	**En.2**	**En.3**
Ec.	/	1.00	2.00	**Ec.1**	/	2.00	0.50	**So.1**	/	1.00	2.00	**En.1**	/	2.00	2.00
So.	1.00	/	1.00	**Ec.2**	0.50	/	0.33	**So.2**	1.00	/	1.00	**En.2**	0.50	/	1.00
En.	0.50	1.00	/	**Ec.3**	2.00	3.00	/	**So.3**	0.50	1.00	/	**En.3**	0.50	1.00	/
w	0.54	0.30	0.16		0.30	0.16	0.54		0.54	0.30	0.16		0.50	0.25	0.25

The final sub-criteria weights are obtained by multiplying the weights of sub-criteria with the weights of the corresponding criteria. The obtained sub-criteria weights are w(Ec.1)= 0.160, w(Ec.2)= 0.088, w(Ec.3)=0.292, w(So.1)=0.160, w(So.2)=0.088, w(So.3)= 0.048, w(En.1)= 0.082, w(En.2)= 0.041, w(En.3)= 0.041.

The next step was to evaluate the CE interest areas in relation to the established sets of sub-criteria and rank them using the COBRA method. Decision matrix is obtained according to the equation (5) (Table 2).

Table 2 Evaluations of the CE interest areas in relation to sub-criteria

	Ec.1	Ec.2	Ec.3	So.1	So.2	So.3	En.1	En.2	En.3
SCM	5	9	7	9	9	8	8	9	8
CBM	9	8	6	5	4	5	6	4	7
PLM	8	4	8	6	3	4	7	3	6
DT	6	3	4	3	7	7	4	6	4
RE	4	6	3	7	2	3	2	2	9
SS	3	5	5	4	6	9	3	7	5
RU/RM/RC	7	7	9	8	8	6	9	8	3

Decision matrix is then normalized using the equations (6) and (7), and weighted using the equation (8). For each criterion function PIS_i, NIS_i and AS_i are obtained using the equations (9), (10) and (11), respectively. By applying the equations (12) - (17) $d(PIS_i)$, $d(NIS_i)$), $d(AS_i^+)$ and $d(AS_i^-)$ distances are obtained for each alternative. By applying the equation (26) dC_i distances are obtained and by arranging them in the increasing order the final ranking of CE interest areas is established. Values based on which the ranking is established, as well as the ranking itself are presented in Table 3. It can be concluded from the results that the most important CE interest area is RU/RM/RC, followed by the SCM and PLM.

Table 3. Final ranking of the CE interest areas

	d(PIS)	d(NIS)	d(AS+)	d(AS-)	dC	Rank
SCM	-0.244	0.508	0.234	-0.209	-0.048	2
CBM	-0.044	0.123	0.029	-0.168	-0.015	4
PLM	-0.218	0.392	0.160	-0.103	-0.034	3
DT	0.441	-0.491	-0.278	0.247	0.056	6
RE	0.596	-0.518	-0.225	0.411	0.069	7
SS	0.355	-0.460	-0.258	0.148	0.047	5
RU/RM/RC	-0.887	0.447	0.338	-0.326	-0.079	1

5.CONCLUSION

The goal of this paper was to identify the CE interest areas which are most affected by the application of the I4.0 technologies for performing the logistics activities within the agri-food sector. After establishing the alternatives, they were evaluated in relation to the defined set of criteria and ranked. For obtaining the criteria weights the AHP method is used, while the COBRA method is used for obtaining the final rank of the alternatives. Results indicated that the RU/RM/RC, SCM and PLM are the interest areas that contribute most to the sustainability of the CE system in the agri-food sector and to which the greatest attention should be paid in the future plans and actions. One of the main contributions of this paper is the investigation of the wider application of I4.0 technologies for performing the logistics activities within the individual areas of the CE in the agri-food sector. Another one is the establishment of a framework for the evaluation and identification of the main interest areas which will be in focus of future plans, actions and development strategies aiming at achieving the sustainable CE in the agri-food sector. Future researches could investigate the applicability of the I4.0 based logistics activities in the main CE interest areas for some other sector. Since CE is a concept that influences multiple stakeholders, future researches could also investigate main CE interest areas priority in relation to the individual aims and goals of the various stakeholders, as well as the compromise priorities in relation to all of their goals.

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INDUSTRY 4.0 AND E-PUBLIC PROCUREMENT: A PROFITABLE COEXISTENCE

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Abstract: *Public procurement is an important component of public finances in the E.U. and the Member States. Therefore, their management is a challenge for the trustworthy relationship of citizens with the public sector authorities. Existing electronic public procurement optimization tools in the E.U., such as T.E.D., electronic forms, e-invoices, and electronic portals of Member States, are systematically attempting to standardize procedures by improving access to information and transparency in its management. Nevertheless, the next day requires the enlightenment of the transition roadmap to modern tools and technologies of the fourth industrial revolution. According to the E.U. objectives achievement degree, the comparison between the existing e-procurement tools 3.0 and the expectations from the possible uses of the emerging technologies 4.0 will indicate the appropriate points where strategic priority should be given through the implementation of the digital transformation process. The study presents this comparative analysis of empirical data based on the relevant literature in e-P.P. 3.0 and current case studies in e-P.P. 4.0 in a summary figure whose logic originated from the Balanced Scorecard and Hoshin Kanri matrix.*

Keywords*: e-public procurement; industry 4.0; emerging technologies*

1. INTRODUCTION

As a critical governmental function, public procurement has the basic goal of supplying products and services in a timely, cost-effective, and efficient way to achieve its missions. The study of public procurement is a field that greatly influences public finances and business activity. Over 250 000 public bodies in the European Union spend roughly 14% of their G.D.P. on services, works, and supplies(European Commission 2019). Rational and transparent management of public finances strengthens citizens' faith in governance. Public procurement is an important part of public finances in E.U. and the Member States, and therefore their management is a challenge for the relationship of citizens with the public sector authorities. The Recovery and Resilience Facility (R.R.F.),€723,8 billion in current prices, the political priorities of the 2021-2027 period, and the COVID-19 pandemic crisis reset the framework of public procurement challenges Industry 4.0

revolution progress. There is a necessity for more transparency and efficiency to manage the spending of R.R.F. and E.U. Strategic Framework 2021-2027 funds at the national level.

E-Public Procurement (e-P.P.) increased transactional efficiency for both providers and governments. Transparency in government procurement reduces government expenses, improves value for money, and reduces corruption. e-P.P. may result in high cost and administrative savings and increased market access and accountability. In this way, e-P.P. contributes to economic growth. In the E.U., it is necessary to forecast how the time and means will be required for the transition from technologies 3.0 to 4.0 to meet the E.U.'s public procurement objectives effectively. The research aims to set the proper priorities in the digital transition from e public procurement 3.0 to e public procurement 4.0. The resources of a digital transition are not unlimited; therefore, strategic priorities should be set. The contribution of this study is to provide the Technology Forecasting as a framework for a debate among experts to design the strategic transition through a Technology Roadmap.

2. SUPPORTING THEORIES AND RELEVANT LITERATURE

2.1 The E.U.'s e-Public Procurement 3.0 goals and tools.

European Commission as the administrative supervisor of the supranational institution seeking to gain a granular view of procurement practices by its member states, thereby enforcing best practice compliance to specific policy axes. The vital role of Public Procurement in the E.U. and its Member States stems from their significant influence on the G.D.P. of Approximately 2 trillion euros and 13% of the E.U.'s G.D.P(Panayiotou, Gayialis, and Tatsiopoulos 2004) and their potential for dynamic integration of strategic parameters into the implementation of public policy. They set critical political objectives such as a) improving the efficiency of public resources by improving business competition, b) ensuring transparency -accountability, and open data. Also, using the procurement framework for defining the needs, specifications, and award criteria, strategic objectives serving social responsibility, environmental protection, and the innovative development of the competitiveness of enterprises. The Directive 2014/24/E.U. is an example that has set new rules in e public procurement about electronic delivery of notifications, electronic access of procurement documents, electronic filing of requests for participation, and tenders. Electronic advertising has been done by e-submission of notices in the Official Journal of the European Union (O.J.E.U.). Tenders are listed on Tenders Electronic Daily (T.E.D.). The Publications Office plays an essential role with two modules: in the reception of notices, a) e-Notification (e-Notices, e-Sentool, and T.E.D.) and b) e-Access refers to electronic access to procurement papers (TED-e Tendering). T.E.D. uses e-Forms, an E.U. legal standard for procurement data, to issue announcements on Tenders Electronic Daily. European Single Procurement Document (E.S.P.D.) makes the public procurement process more accessible. It is a self-declaration of a company's eligibility, financial position, and capabilities used as preliminary evidence in all public procurement procedures over the E.U. threshold. E-Certis is the mapping application that assists participants in public procurement operations in identifying and comparing various certifications required in procurement procedures across the E.U. It is integrated with E.S.P.D. Open e-PRIOR is a free, open-source e-Procurement platform that enables government agencies to build interoperable electronic services. E-Invoicing Directive established a European standard for e-invoicing to solve the issue of e-invoice format diversity. E-invoicing is quite mature but not entirely implemented and monitored by the member states.

2.2 The emerging Technologies in e-P.P. 4.0.

The Study of the Directorate-General for Internal Market, Industry, Entrepreneurship, and S.M.E.s about emerging technologies in public procurement worldwide is an important base for our research (Deloitte and European Commission 2020). Emerging technologies have the potential to revolutionize public procurement. New technology can allow smarter decisions, save costs, and promote transparency by automating repetitive administrative tasks and providing remarkable data analysis on spending patterns and supply project execution. Big Data Analytics (B.D.A.), Business Intelligence (B.I.), Machine Learning (M.L.) and Artificial Intelligence (A.I), Blockchain, Internet of Things (IoT), Robotics Process Automation(R.P.A.), Augment Reality and Virtual Reality, 3D Printing are the Industry 4.0 (I.D 4.0) emerging technologies that there are current cases studies (Accenture 2019; World Bank 2021).

2.3 Innovation diffusion Theory (Model)

Many studies have found that key perceptions of technological traits, referred to as innovation, impact technology adoption choices. The objective of innovation diffusion theory is to comprehend the mechanism through which inventions spread within a social system(Rogers 1995). Rogers (1995) lists five criteria of an invention generic to the degree of adoption in a social system. Relative advantage, compatibility, complexity, observability, and trialability are some of these critical variables. Relative advantage can be operationalized or assessed regarding the innovation's utility in achieving work goals, the quality of work results, increased convenience, and social prestige. To measure relative advantage, we selected E.U.'s public procurement goals. So, in this way, we can find the level to which the emerging technologies of ID 4.0 are superior to the current e-P.P E.U.'s tools.

3. METHODOLOGY, RESEARCH DESIGN

In order to facilitate the forming of the study, we focus our study on the public procurement area of the Member States of the European Union and define as a criterion for comparing efficiency the objectives set by the Commission itself regarding public procurement. The Technology Forecasting (T.F.)(Quinn 1967) about emerging technologies and e-P.P. must eventually anticipate whether technical systems will be able to attain or exceed important performance levels or parameters by a specific date in the future. The selection and prediction of these characteristics are thus at the heart of the forecasting process. The chosen criteria to check technological potentials and the diffusion of the emerging technologies in e-PP are a)the relative advantage of e-P.P. 4.0 technologies in satisfying the main public procurement goals. The chosen criteria (variables) are based on the Innovation Diffusion Theory (Model)(Rogers 1995). The tools of the existing technologies that were examined concerning the implementation of the above objectives were applied or have been launched to be applied shortly.

The comparative theoretical analysis of the influence of existing e-procurement tools on those of emerging technologies has two sources.A)The ontological potentials derived by definition from the previous studies' theoretical approaches of the previous studies.B)The empirical findings coming from relevant case studies. The combination of the two above results is summarized in an estimation comparative evaluation scale representing the degree of influence in achieving the goals between -1 and 2. With -1 the specific tool or technology has no influence or correlation with the specific goal. With 0 the correlation will be neutral. With 1 the additional influence is small, and with 2 the additional influence is large and immediate in achieving the goal. If we do not have sufficient data, we place the letter x. The sum grade shows the comparative priority by examining the potential relative advantage of emerging technologies compared to current e-P.P. 3.0 EU's tools.

The main research question of this study is:

The evaluation of the impact of applicable e-public procurement technologies 4. based on current cases in Industry 4.0 according to:

I. E.U. public procurement goals. (relative advantage)

The outcome is a summary figure representing the estimation conducted by literature review and case studies. The study results are presented in a summary figure which is a hybrid construction of the Balanced Scorecard and Hoshin Kanri matrix (Dias and Tenera 2020).This is the proper base to reach Technology Roadmapping (T.R.M.) through Technology Forecasting (T.F.).Martino defines it as: “A prediction of the future characteristics of useful machines, procedures or techniques”(Martino 2003). The necessity for technology forecasting is critical for successful technology transfer.

A Future-oriented technology analysis method based on expert opinion(Delphi) of this study's estimation figure could support a proper Technology Roadmapping (T.R.M.) (Porter 2010). A technological roadmap will outline when the previous system will be phased out and when the new one will be put in place. A technological roadmap will assist policymakers in determining which technologies to advance and how to put them into practice (Harold A. Linstone and Murray Turoff 2008).

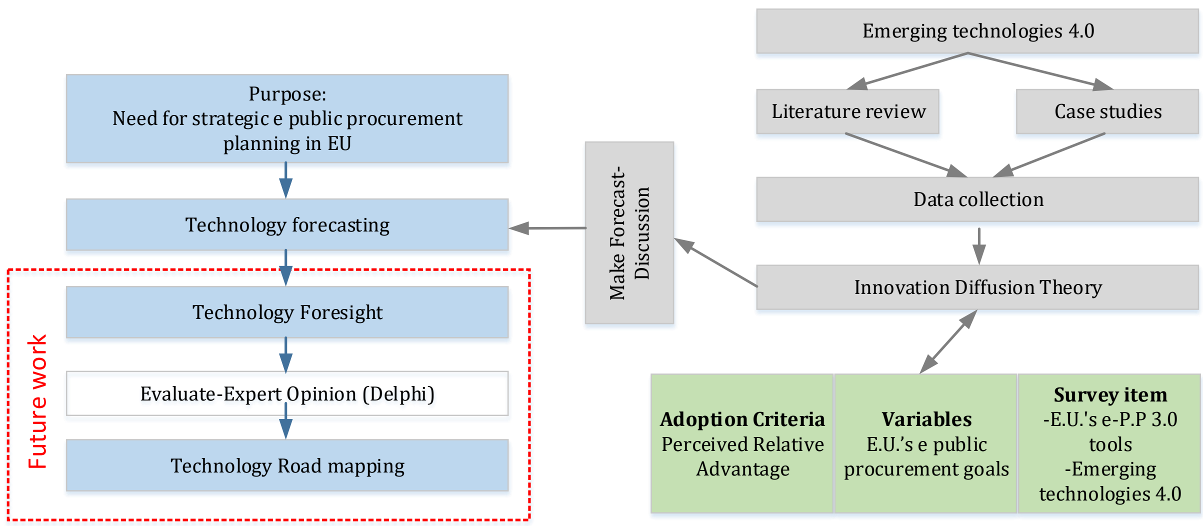

Figure 1. Current and Future research concept map.

4. Data Discussion

The concluding analysis of the literature results and the recording of case studies follow at this point in the study. Its visual representation is summarized in Figure 2. The given model will be accepted, challenged, or completed at a future research stage by using the Delphi method(Harold A. Linstone and Murray Turoff 2008).

1.Trasparency/ security/accountability (Europe closer to citizens)	2.Equal treatment/opportunities for SMEs/cross border trade (Competive Europe)	3.Reduce Fraud Corruption	4.Remove legal and administrative barries	5.Green Procure (Greener Economy)	6.Social Procure (Social and Inclusive Europe)	7.Innovation(Smarter Europe)	Total Score	**B.Strategic goals in Public Procurement 2014-2020_Policy Priorities/Objectives 2021-2027**
								A.e- public Procure 4.0
2	2	2	2	1	1	1	11	1.Blockchain
2	2	2	1	2	2	2	13	2.Big Data
2	2	2	2	2	2	2	14	3.Business Intelligence
1	1	1	1	2	2	2	10	4.Artificial Intelligence-Machine Learning
2	0	1	0	2	0	2	7	5.Internet of Things (IoT)
1	0	2	2	1	1	1	8	6.Robotic process automation
1	1	1	1	1	0	2	7	7.Augmented Reality and Virtual Reality
1	1	0	0	1	1	1	5	8.3D printing

	corellation/contribution/impact
-1	negative
0	neutral
1	indirect/low/relatively positive
2	direct/high/positive
X	no evidence more research needed

Figure 2. Summary of visualized comparative analysis between e public procurement technologies 3.0 E.U. and 4.0., according to E.U.'s objectives

4.1 Blockchain and E.U.'s goals.

A1.B{1-4} A blockchain is a form of digital trust(Bertrand Maltaverne 2018). Blockchain has a critical impact on transparency, equal treatment, reducing fraud, and removing bureaucratic barriers because when blockchain technology is used in procurement creates a "data backbone."(Deloitte and European Commission 2020; Iansiti and Lakhani 2017).As a "data backbone" that can be used to foster interoperability, paving the way for increased automation and "interconnections" between physical and financial supply chains(Bertrand Maltaverne 2018).

A1.B {5-7} The green social and innovative criteria could be satisfied if we examine, for instance, the case of Digipolis as an "experimental procurement" in Uyarra and Flanagan's four-fold typology. This means that it involves the procurement of adapted technical (software) solutions, where the supply of inputs comes from a "community of specialists" (i.e., the startup community) and the clients' demands are precise and heterogeneous (i.e., the Antwerp public sector)(De Coninck, Viaene, and Leysen 2018).

4.2 Big Data Analytics and E.U.'s goals.

A2.B1 Big data visualizations contribute to the complete understanding of data content easily and comprehensively, adding value to transparency as critical information comes to the shareholders(Auditors 2019)

A2.B2 Market research is more reliable and quicker because it is not dependent on suppliers but the contracts. This accurate market research supports economic efficiency, equal treatment**,** and the improvement of procurement planning (World Bank 2021).

A2.B3. It is possible with big data analytics to flag high-risk sections for more investigation or suspicious transactions for audit or additional inquiry (Mihály Fazekas et al. 2018).

A2.B{5-7} The methodology of preparing the big data before they are analyzed helps prevent distortion of data from various sources. Big data analytics facilitate benchmark quick and trustworthy participation requirements, award criteria, subcontracting conditions, and contract modifications, so there is a positive relation between green social and innovative procurement (Babica, Sceulovs, and Rustenova 2019).

4.3 Business Intelligence and E.U.'s goals.

A3.B{1-4}Business Intelligence contributes to the availability of information in the form of understandable graphs, diagrams, and charts that appears to be more precise and opens up more opportunities for deep and significant understanding to all stakeholders. Bidders, for example, may monitor how much their governments spend (transparency), what they spend it on, how long the procurement process takes, where the bottlenecks are, and how projects and services are procured and delivered using B.I. (OCDEX 2020). Obtaining these patterns and insights gives suppliers, contractors, and locators a strategic edge in planning bids or determining whether to invest in a certain local government depending on the procurement trends(Williams 2016).

A3.B{5-7) B.I. can transform data into useful, real-time, fact-based information that aids and simplifies decision-making. This capacity can assist Public Authorities and businesses in resolving some long-standing information-related issues. It also informs suppliers about the criteria used to evaluate themselves and their competitors, fostering competitiveness. These criteria could be green social or innovative as key metrics (Williams 2016)**.** For instance, the BI Prozorro module may filter, classify, and analyze data using dozens of criteria in each part(Bugay, Yuriy 2016).

4.4 Artificial Intelligence, Machine Learning and E.U.'s goals.

A4.B{1-2} Suppose we avoid getting caught up in algorithms that lead to "black boxes" and promote our request to suppliers in a clear and explanatory way. In that case, we certainly have a practice that directly contributes to transparency and fair distribution of opportunities (Acemoglu and Restrepo 2018). The predictive information that a system creates by collecting data, e.g., Tender documents, and organizing them in patterns increases transparency in public procurement (Ash, Galletta, and Giommoni 2020).

Technical and procedural explainability are the critical parameters to ensure transparency and equal opportunities.

A4.B3. Using machine learning algorithms, A.I. as a risk analysis selector can monitor vast amounts of public tender data and detect any irregularities, such as unexpected changes in purchase prices and fraud complaints. A.I. can gather and analyze millions of various data sources to create a clearer picture of procuring entities' and bidders' characteristics and habits, allowing them to determine and forecast whether or not a certain partner is trustworthy(Iain Batty and Veronika Kovács 2020).

A4.B{3-4} Although the empirical research is limited, algorithmic governance can produce predictions or risk scores and help through decision support the elimination of bureaucratic barriers (Goldenfein 2019). Another practical case refers to extracting data from contracts and invoices with A.I. Moreover, for example, an advanced chatbot has the potential to become the single point of contact for internal and external queries. In this way, A.I. can reduce both fraud and bureaucracy (Deloitte 2020; Surya 2019)

A4.B{5-7} There are records where machine learning can help support procurement decisions in public bodies using multi-criteria methods. So this means that it is possible to integrate environmentally innovative and community-based criteria into public procurement (Goldenfein 2019). A.I. may assist public purchasers in finding the green or sustainable public procurement criteria that will produce the greatest improvements assessed against any key performance indicator, such as CO2 footprint (Gailhofer et al., 2021). Generally, A.I. overcomes human information processing limitations and helps generate innovations in public procurement (Haefner et al. 2021).

4.5 Internet of Thinks (IoT) and E.U.'s goals.

A5.B1 IoT provides real-time access to public procurement information and increases efficiencies and transparency (Micheli, M et al. 2019; Wirtz, Weyerer, and Schichtel 2019).

A5.B3 Tracking the inventory items' position and receiving low-stock alerts or notifications if a product is missing by introducing linked sensors and data storage systems. Allowing you to rapidly and precisely acquire product data across the supply chain reduces the fraud possibilities in setting a need for purchase (Micheli, M et al. 2019; Wirtz, Weyerer, and Schichtel 2019).

A5.B5 Discerning circular economies and green procurement because IoT could confirm purchasing criteria while using the product (Legenvre, Henke, and Ruile 2020).

A5.B7 Augmented reality cases potentially help plan a project as well as we can collect, analyze and visualize data and interact with them by making several scenarios. The progress of complex and dynamic ecosystems between IoT big data analytics and A.I. support strategic partnerships and contribute to innovation (Alam, Vats, and Kashyap 2017; Micheli, M et al. 2019)

4.6 Automation R.P.A. and E.U.'s goals.

A6.B1. Subjective feelings have no effect on bots, which provide objective and transparent output based on predetermined criteria. R.P.A. adopters and consultancies agreed that the rate of process mistakes lowers dramatically and tends to zero if the bot is properly programmed(Flechsig, Anslinger, and Lasch 2021).

A6.B2. R.P.A. tendering standardization; increased openness(Flechsig, Anslinger, and Lasch 2021; R. Uskenbayeva et al. 2019) and allows S.M.E.s for fair participation in e-P.P.

A6.B3. R.P.A. bots can perform data processing, transfer, and administration activities, preventing unauthorized access to sensitive information, applying anti-fraud checks and special filtering award criteria (Flechsig, Anslinger, and Lasch 2021; R. Uskenbayeva et al. 2019).

A6.B{5-7} R.P.A. could help public sector enterprises with service specifications, i.e., bots would create predetermined parts of the description and process standard tenderer requests. These predetermined criteria in tendering and supplier evaluation phase could be green, social, or innovative (Flechsig, Anslinger, and Lasch 2021; R. Uskenbayeva et al. 2019).

A6.B7 R.P.A. accelerates the continuous digital transformation and shift of e-PP from its traditional operational position to a more strategically oriented and involved business function by facilitating an innovative corporate culture(Van Poucke et al., 2019).

4.7 Augmented - Virtual reality and E.U.'s goals.

A7.B{1-3}. Augmented reality can contribute to transparency, and the fight against corruption in public procurement as the simulation of public projects can involve citizens in some planning choices. They are checking the correct execution of the terms of a contract afterward during the implementation of a public project (Bakken 2018).

A7.B{2,4}. The contribution of augmented reality to creating business opportunities and removing administrative barriers may not be directly demonstrated through specific projects. Still, there is a possibility that potential suppliers will be able to have better information, even though from a distance, on the specifications and the distinct nature of a public contract project(Gregory Curtin 2017).

A7.B{5-7} A.R. is, by definition, green technology as it reduces the environmental footprint that would create some wrong choices in public works or goods procurement and optimizes the final decisions through scenarios by choosing the most innovative solutions. Augmented reality cases potentially help plan a project as well as we can collect, analyze and visualize data and interact with them by making several scenarios endorsing several criteria green, social, innovative(Accenture 2019; Deloitte and European Commission 2020; Gregory Curtin 2017).

4.8 3D Printing and E.U.'s goals.

A8.B1 At Deutsche Bahn Group, critical printing spares now have a viable alternative for buying spare components, boosting its bargaining strength with suppliers and lowering procurement costs(Josephine Cordero Sapién 2021).

A8.B2 3D printing is a small-scale production process used by small and medium-sized businesses. However, it is not certain that they will have the requisite capital resources or expertise to compete in this area. Additionally, Additive Manufacturing (AM) enables total design freedom and local, flexible production (Berman 2012; Ngo et al. 2018).

A8.B5. 3D Printing prototypes contribute to evaluating the viability of several alternatives and may refine the service concept, create a service offer for a new or enhanced service, or select the proper one according to the final results. This technique is naturally ecologically beneficial since it lowers the quantity of material wasted and optimizes the proper good or supplier (Berman 2012; Shuaib et al. 2021).

A8.B6 3D printers allow small E.U. social enterprises to engage in supply competitions with specific creative ideas by producing prototype projects or manufacturing customized items to fulfill an order for a Public Authority (Ngo et al. 2018).

A8.B7 By shortening the trip from an abstract concept to a physical item, 3D printing offers new avenues for invention and creativity by transforming data into products and from products data (Shuaib et al. 2021).

5. CONCLUSION

Procurement is a strong instrument for government agencies to spend public funds in an effective, transparent, sustainable, and strategic way.

Emerging technologies in ID 4.0 offer the opportunity to rethink how public procurement is organized completely. However, we can not ignore the opportunities that new technologies can create in public procurement. The transformation roadmap should optimize current technologies and tools compared to emerging technologies. This study contributes as the first step to future dialogue between experts about which emerging technologies are more effective and compatible to serve the goals and the public procurement operational stages. The technologies with the greatest overall comparative influence in achieving the goals related to public procurement in the E.U. using emerging technologies are Business Intelligence, Big Data Analytics, Blockchain, and Artificial Intelligence-Machine Learning. The common feature of the former technologies is related to their structural ability to support in the procurement process critical areas of decision making. The decision-making process consists of the collection, filtering, analysis, formation, and comparative performance of alternatives, with the ultimate goal of selecting the best possible procurement process that achieves the strategic goals of E.U.

The significant contribution to the literature in using this analysis model is that it prepares a Technology Forecasting path by using the relative advantage from Innovation diffusion Theory (Model) as a variable. The limitation of this model results is that it is only applied theoretically based on literature review and case studies. Further research using Delphi Method will help test the validity of the results and integrate this model with managerial implications and a Technology Road-mapping framework for the public and private sector shareholders. The estimates presented for each type of technology with the type of goal they serve may be revised in the future with the implementation of new case studies. However, the specific characteristics of some technologies make them more efficient in all strategic objectives of the E.U.

Nevertheless, this does not mean that possible synergies cannot lead to cumulative results with a higher rate of return on achieving each goal separately. A profitable transition to public procurement 4.0 in the European Union cannot be done without priorities and randomly. Therefore, mapping all possible points drawn from any technology and their potential interdependencies should be a dynamic field of continuous research and optimization.

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TASK OFFLOADING IN A SECURE MOBILE EDGE COMPUTING ENVIRONMENT FOR INDUSTRIAL APPLICATIONS

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Abstract: *The emerging intelligent applications in an industrial environment are highly computation-consuming. Smart devices without sufficient computing resources cannot support these applications. Task offloading to the Mobile Edge Computing (MEC) servers can be an appropriate solution to improve the performances in terms of delay sensitivity and security. To maximize the utility of the system, resource allocation should be considered simultaneously. In this paper, we propose a novel Deadline-Aware Task Offloading (DATO) scheme based on the double Vickrey-Clarke-Grove (VCG) auction in a secure MEC environment for industrial applications. The effectiveness of the proposed scheme is compared to the classic Greedy Task Offloading (GTO) scheme. The extensive simulations show that the proposed task offloading scheme is equally efficient in terms of utility, but concurrently improves performances in terms of time-out failures. Furthermore, the applied auction mechanism in the observed task offloading problem assures individual rationality and truthfulness.*

Keywords: *industrial applications, mobile edge computing, task offloading, auction, security.*

1. INTRODUCTION

Industrial applications require the use of smart objects capable of monitoring, collecting, analyzing and making intelligent decisions in an industrial setting. With the emergence of Industry 4.0, manufacturing industry scenarios are focused on the digitization and integration of all physical processes across the entire organization, according to Sengupta et al. (2021). Thus, smart factories and logistic centers can effectively handle the growing complexities. Innovations should make industrial ecosystems more robust and scalable. However, it is necessary to extend the features of cloud services to the end devices and enable local processing of tasks in a timely manner. Smart industrial devices have limited computing capabilities. Moreover, processing on the cloud causes a large response time, disruptions in the underlying communication networks and security issues. One of the

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effective solutions is to introduce a middleware computing resource, such as Mobile Edge Computing (MEC) to support local task processing instead of processing in the devices or remote cloud server. MEC servers are usually owned by different authorities and profit-driven, according to Luo et al. (2019). Therefore, the offloading cost is imposed on smart devices for task execution on MEC servers.

Auctions are often used as promising solutions for fair distribution in various edge-computing domains, including MEC, Fog Computing and Cloud Computing. Double auctions can efficiently balance the incentives of all relevant participants, including buyers and sellers. Buyers place their bids (their willingness to pay for used resources), while sellers place asks (the minimum required price per resource provided). Specifically, the double Vickrey-Clarke-Grove (VCG) auction is a convenient tool to provide incentives for truthful bidding in the task offloading process in an industrial MEC environment.

In this paper, we observe a general industrial scenario, with several MEC servers in a smart factory or logistics center. Smart devices, including mobile robots, Automated-Guided Vehicles (AGV), smart cameras etc., generate multiple computation-sensitive tasks with heterogeneous constraints on their delay tolerance. These tasks should be offloaded to the MEC servers to improve the system's performance. However, task offloading introduces several issues, including security, heterogeneity of demands and incentives for resource provision. The main contributions of this paper are the following: (i) we propose a novel deadline-aware task offloading scheme to reduce the number of time-out failures in task execution on MEC servers; (ii) we set truthful VCG-based double auction that satisfies individual rationality and provides incentives for task offloading; (iii) simulation results show the effectiveness of the proposed model and improved performances compared to the classic greedy algorithm.

The remainder of the paper is organized as follows. The related work is discussed in Section 2. The proposed system model and problem formulation for the two various double VCG auction-based task offloading schemes are presented in Section 3. In Section 4, we present performance evaluation and discuss simulation results. Finally, Section 5 provides concluding remarks and future research directions.

2. RELATED WORK

Task offloading provides low latency, high bandwidth and stability for the mobile computing scenarios, according to Wang et al. (2018), Cao et al. (2019) and Feng et al. (2019). A price-based distributed method is used by Liu and Liu (2018), to schedule offloaded computation tasks. The Stackelberg game is used to obtain equilibrium and maximize the utilities of both MEC servers and users. The communication cost for task offloading along with the optimization of computing resources is addressed by Al-Shuwaili and Simeone (2017). A multi-queue model is proposed by Zhang et al. (2019), to observe the effects of offloading schemes on the performance of IoT devices combined with their assigned edge computing server. Industrial applications usually pose strict requirements on task offloading, especially in terms of security and latency. However, security requirements are often neglected, according to Zhang et al. (2018), Zhou et al. (2019), and Tran and Pompili (2019), while deadline considerations are often decoupled with resource sharing for MEC servers, according to Zhang (2017) and Alameddine et al. (2019).

Auctions can be effectively used to provide incentives for task offloading in the MEC environment. An adaptive task offloading auction model is proposed by Luo et al. (2019), where the offloading problem is addressed under the access capabilities, latency and security constraints. To allocate edge servers to mobile devices, an auction executed by a pair of deep neural networks is proposed by Mashhadi et al (2020). The results show that the auction mechanism maximizes the profit of the edge servers and satisfies the task processing delay and energy consumption constraints of the mobile devices. Due to the use of deep neural networks, mobile devices are unable to unfairly affect the results of the auctions. A multi-part collaborative task offloading with multiple servers in MEC systems is analyzed by Zhang et al. (2022), to optimize server overload and long-term performance. In this paper, resource allocation on MEC servers is jointly observed with deadline and security considerations in task offloading problem. The truthful double VCG-based auction mechanism is established between the participants, thus providing incentives for MEC servers to enable task offloading.

3. SYSTEM MODEL AND PROBLEM FORMULATION

The proposed architecture for task offloading in the MEC environment for industrial applications is shown in Figure 1. The framework supports a system with heterogeneous MEC servers and IoT devices (mobile robots, AGVs, smart cameras, etc.) that offload computation tasks to MEC servers.

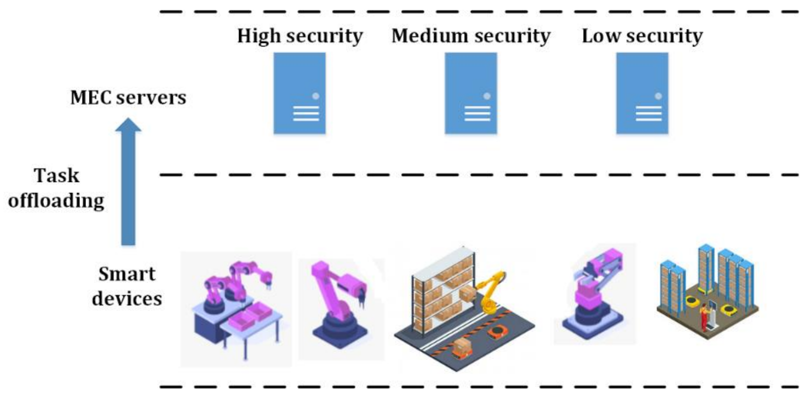

Figure 1. The architecture of the secure industrial MEC environment

The proposed framework can be used in realistic scenarios, smart factories, logistics centers etc., where, for instance, smart (IoT) devices equipped within the assemble lines in a factory offload computation tasks to its neighboring MEC servers. The user, i.e., the IoT device chooses the appropriate MEC server to offload tasks based on the required security level. The selected MEC server decides how to schedule the offloading tasks with various deadline constraints. The determination of the tasks to be provisioned by the MEC server is performed using VCG-based double auction. The MEC server acts as the seller, sharing its computation resources. Each IoT device acts as the buyer that offers the monetary payment to offloaded MEC server.

The proposed architecture comprises three MEC servers, $j \in \{1,2,3\}$, and each server provides a low, medium or high-security level, respectively. At the beginning of each time slot, an active IoT device generates a computation task to be offloaded to the corresponding MEC server. The number of active IoT devices in the time slot $i \in [1, N]$

generating the request for task offloading to the selected MEC server j is denoted by $E_{i,j}$. The arrival rate of tasks to be provisioned follows a Poisson distribution with the average input rate λ. All requests generated by active IoT devices are computationally independent. To initiate task offloading, an IoT device submits a bid to the MEC server. We assume that each active IoT device in a given time slot generates a single request for task offloading, and each task can be executed within a single time slot. The task can be expressed as the following tuple:

$$e_{i,j} = \left(\gamma_{e_{i,j}}, \tau_{e_{i,j}}, b_{e_{i,j}}\right) \tag{1}$$

The parameter $\gamma_{e_{i,j}}$ in (1) describes the computation resources, expressed in capacity units, that task $e_{i,j}$ occupies on the selected MEC server. $\tau_{e_{i,j}}$ denotes the delay tolerance, expressed in time slots, while $b_{e_{i,j}}$ denotes the value of the bid (in monetary units) per required capacity unit of the MEC server j. The bid is a nonnegative value and represents the true willingness to pay for task execution. It is important to emphasize that an IoT device is not being charged by the value of the bid, but by the value that is less or equal to the bid. The payoff is defined in an auction process. It is assumed that bids are independent, and there is no information on other bid values in the auction.

At the beginning of each time slot, the values of asks per capacity unit for each MEC server, denoted by $\alpha_{i,j} \in \left(\alpha_{i,j}^{\min}, \alpha_{i,j}^{\max}\right)$, are defined. The minimum ask, $\alpha_{i,j}^{\min}$, represents the cost per capacity unit for task provisioning. To prevent predatory bidding, the maximum ask per capacity unit is limited to the $\alpha_{i,j}^{\max}$. Once bids of all active bidders are placed and corresponding asks of MEC servers are defined, the determination of candidates for winning bidders is performed. The set of winning bidders is determined depending on the chosen task offloading scheme. We assume that the queue length, denoted by L, represents the number of tasks waiting for the execution.

3.1 Greedy task offloading scheme (GTO)

Set of all requests for task offloading to the chosen MEC server j consists of requests generated in the current time slot and the tasks from the queue determined in the previous time slot. Candidates for task execution are all requests with the bid value that is greater than or equal to the value of the ask for the given MEC server, i.e., $b_{e_{i,j}} \geq \alpha_{i,j}$.

Afterwards, the candidate tasks are sorted in the non-increasing order by the values of the bids. Tasks from this sorted set are added to the winning set of the tasks until there is enough capacity for the given MEC server. Thus, for each winning task in the greedy task offloading scheme $\omega_{i,j}^{GTO} \in W_{i,j}^{GTO}$, applies:

$$\omega_{i,j,m}^{GTO} \geq \omega_{i,j,m+1}^{GTO}, \quad \sum \gamma_{\omega_{i,j,m}^{GTO}} \leq \Gamma_j \tag{2}$$

In (2), m denotes the position of the winning task in the set $W_{i,j}^{GTO}$, while Γ_j denotes the capacity of the MEC server j expressed in capacity units. All other tasks, apart from the winning tasks, are candidates for the queue. These tasks are firstly sorted in the non-increasing order by the value of their bids per capacity unit. Afterwards, the tasks from this ordered set are placed in the queue, until the queue length is exceeded. The queue of tasks waiting for task provisioning $q_{i,j,l}^{GTO} \in Q_{i,j}^{GTO}, l \in [0, L]$ can be expressed as follows:

$$q_{i,j,0}^{GTO} \geq \cdots \geq q_{i,j,l}^{GTO} \geq \cdots q_{i,j,L}^{GTO}$$
(3)

For each task in the queue $Q_{i,j}^{GTO}$, the parameter depicting delay sensitivity is decremented by one. Furthermore, all tasks whose delay sensitivity is decremented to zero ($\tau_{q_{i,j}^{GTO}} = 0$) are removed from the queue, i.e., time-out failure occurs. The number of candidate tasks removed from the queue due to the time-out failure is denoted by $f_{i,j}^{GTO}$. Thus, the total number of time-out failures for the MEC server j can be expressed as follows:

$$F_j^{GTO} = \sum_i f_{i,j}^{GTO} \tag{4}$$

The price to be paid per offloaded task is determined using the VCG-based double auction. Each winning task is charged depending on the bid value of the next winning task in the ordered set of winning tasks and the resources occupied on the corresponding MEC server. Hence, the price for each offloaded task $\omega_{i,j}^{GTO} \in W_{i,j}^{GTO}$ can be expressed as:

$$p_{\omega_{i,j,m}^{GTO}} = \begin{cases} b_{\omega_{i,j,m+1}^{GTO}} \cdot \gamma_{\omega_{i,j,m}^{GTO}}, & if\ \exists \omega_{i,j,m+1}^{GTO} \\ b_{\omega_{i,j,m}^{GTO}} \cdot \gamma_{\omega_{i,j,m}^{GTO}}, & otherwise \end{cases} \tag{5}$$

As shown in (5), the price for task offloading is always less than or equal to the value of the bid for the given task.

The utility function for each MEC server j represents the difference between the offloading price and the ask determined in the current time slot. Thus, the utility can be expressed as follows:

$$U_j^{GTO} = \sum_i \sum_m p_{\omega_{i,j,m}^{GTO}} - \alpha_{i,j} \cdot \gamma_{\omega_{i,j,m}^{GTO}} \tag{6}$$

3.2 Deadline-aware task offloading scheme (DATO)

Deadline-aware task offloading scheme is proposed to improve user experience in the task offloading process and to reduce the number of time-out failures. Similar to the GTO scheme, the set of the candidate tasks for task offloading are all tasks generated in the current time slot and all tasks waiting in the queue from the previous time slot whose bid values per capacity unit of the selected MEC server is greater than or equal to the value of the ask per capacity unit for the given MEC server. Afterwards, the candidate tasks are classified depending on their delay sensitivity, and the values of the bids. Thus, the highest priority in task offloading is assigned to the tasks with the most critical value for the delay tolerance. The candidate tasks with the same priority in terms of delay tolerance are further sorted in the non-increasing order of their bids. Hence, the DATO scheme concurrently addresses both generated utility and deadline awareness.

The candidate tasks from the sorted set are assigned to the winning set until the capacity of the corresponding MEC server is not exceeded. Thus, for each winning task $\omega_{i,j}^{DATO} \in W_{i,j}^{DATO}$ applies:

$$\omega_{i,j,m}^{DATO} \geq \omega_{i,j,m+1}^{DATO}, \quad \tau_{\omega_{i,j,m}^{DATO}} \leq \tau_{\omega_{i,j,m+1}^{DATO}}, \quad \sum \gamma_{\omega_{i,j,m}^{DATO}} \leq \Gamma_j \tag{7}$$

Similar to the GTO scheme, the parameter m in (7) denotes the position of the winning task in the set $W_{i,j}^{DATO}$, while Γ_j denotes the capacity of the MEC server j expressed in capacity units. The candidate tasks for queue placement (all tasks apart from the winning tasks in the current time slot) fill in the queue until the queue length is exceeded, i.e.,

$$q_{i,j,0}^{DATO} \geq \cdots \geq q_{i,j,l}^{DATO} \geq \cdots q_{i,j,L}^{DATO} \tag{8}$$

The delay tolerance parameter for each task in the queue is decremented by one, while all tasks whose delay tolerance has expired ($\tau_{q_{i,j}^{DATO}} = 0$) are removed from the queue, thus increasing the number of time-out failures, denoted by $f_{i,j}^{DATO}$. Therefore, the total number of time-out failures for the MEC server j can be expressed as follows:

$$F_j^{DATO} = \sum_i f_{i,j}^{DATO} \tag{9}$$

The price to be paid per offloaded task is set using a VCG-based double auction mechanism, i.e., each winning task is charged depending on the bid value of the next highest winning task and the occupied resources on the selected MEC server. Thus, the price can be expressed as follows:

$$p_{\omega_{i,j,m}^{DATO}} = \begin{cases} b_{\omega_{i,j,m+1}^{DATO}} \cdot \gamma_{\omega_{i,j,m}^{DTO}}, & if\ \exists \omega_{i,j,m+1}^{DATO} \\ b_{\omega_{i,j,m}^{DATO}} \cdot \gamma_{\omega_{i,j,m}^{DATO}}, & otherwise \end{cases} \tag{10}$$

The utility function for each MEC server j can be represented as the difference between the offloading price and the MEC server's ask in the current time slot. Hence, the utility can be expressed as follows:

$$U_j^{DATO} = \sum_i \sum_m p_{\omega_{i,j,m}^{DATO}} - \alpha_{i,j} \cdot \gamma_{\omega_{i,j,m}^{DATO}} \tag{11}$$

4. PERFORMANCE EVALUATION

To analyze the performances of the proposed auction-based task offloading scheme, we performed a set of simulation experiments in the open-source programming language Python 3.7 in 1000 iterations. The proposed DATO scheme is compared with the GTO scheme in the VCG double auction-based process in terms of the utility of MEC servers and the number of time-out failures.

4.1 Simulation setup

In this evaluation study, we consider a network composed of three MEC servers ($j \in \{1,2,3\}$); each MEC sever has 100 capacity units available at the beginning of each time slot. We assume that MEC server $j=1$ provides a low-security level, MEC server $j=2$ provides a medium security level, and finally, the MEC server $j=3$ provides a high-security level. The assumed computation capacity for each MEC server is 100 capacity units. The analysis is performed in $N=27$ time slots of one-hour duration for 30 days. The first three-time slots represent a warm-up period and these slots are not included in the simulation results. The average number of IoT devices in the observed industrial environment takes values from the set (100, 200, 300, 400, 500), while the number of the active IoT devices that generate requests for task offloading is modeled by the Poisson distribution with the average input rate $\lambda=2$. Selection of the appropriate MEC server, i.e., the security level for task offloading is performed randomly. The queue length for each MEC server takes values from the set (50, 100, 150, 200, 250).

4.2 Number of the time-out failures

We observe the number of time-out failures depending on the selected task offloading scheme, the number of IoT devices and the length of the task queue, as shown in Figure 2.

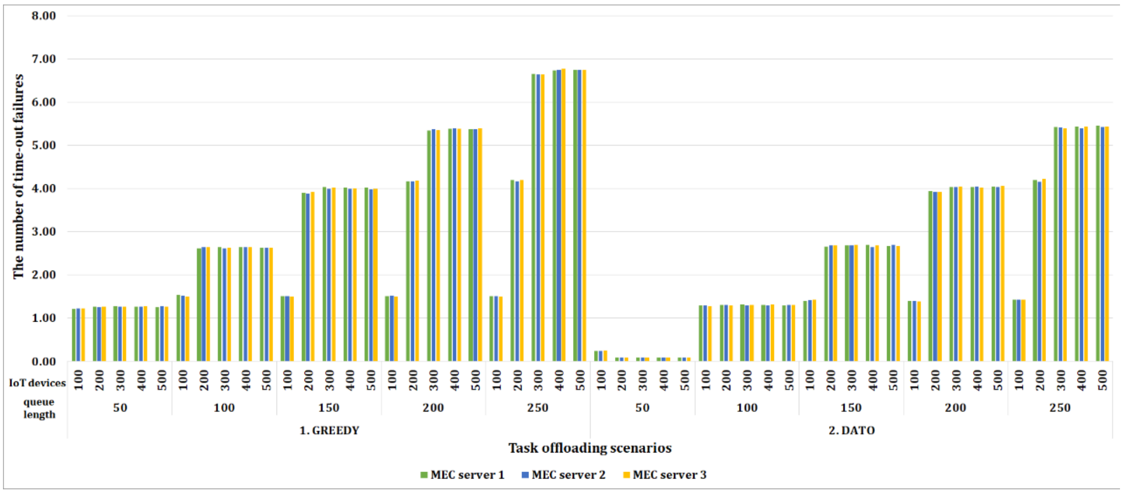

Figure 2. The number of time-out failures

These results apply to each MEC server. It should be emphasized that the proposed DATO scheme provides a lower rate of time-out failures in all scenarios. When the number of active IoT devices in an industrial environment increases, the number of time-out failures also increases, regardless of the length of the task queue. As the length of the queue increases, the number of failures increases, as well. The greatest rise in the number of failures occurs when the number of active IoT devices increases from 100 to 300 on average, for the largest observed queue length and both task offloading schemes. Afterwards, the number of time-out failures follows the saturation trend and remains on the same level. For shorter queue lengths, the saturation level is achieved even for the lowest number of active IoT devices.

4.3 The utility of MEC servers

The utility of MEC servers (expressed in monetary units) mainly depends on the selected security level. A higher security level imposes higher asks per server's capacity unit, thus generating greater overall utility. In both analyzed task offloading schemes, the queue for task offloading is formed in a non-increasing order by the value of the bids. The GTO scheme is purely greedy and assures the greatest utility regardless of the tasks' delay sensitivity. The proposed DATO scheme considers delay tolerance of each task, thus improving users' experience in the task execution process. It should be emphasized that the DATO scheme maintains nearly the same overall utility as the GTO scheme for each security level, as shown in Figure 3.

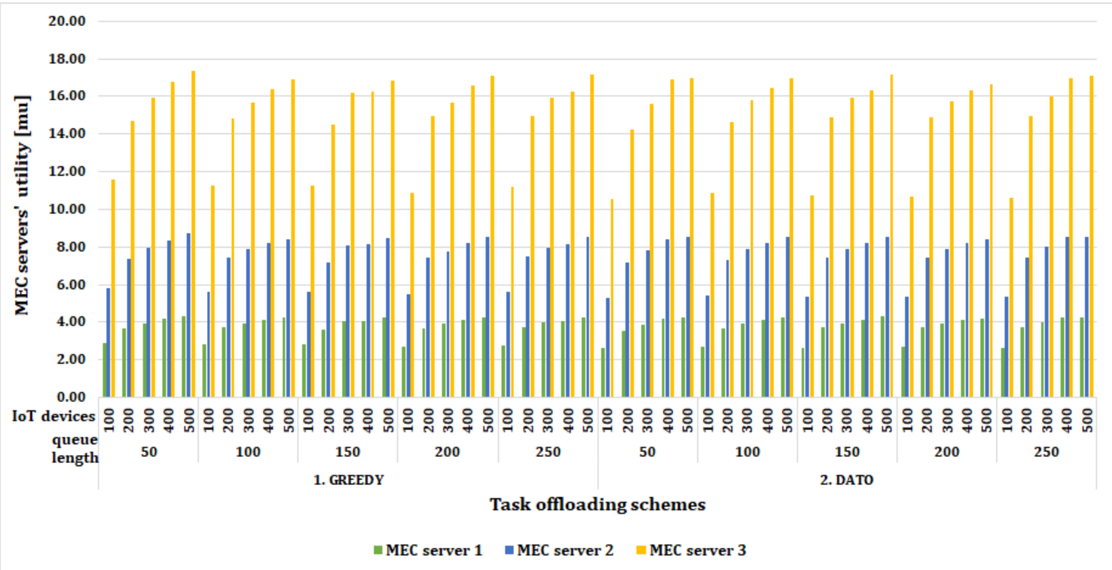

Figure 3. The MEC servers' utility

The utility increases as the number of active IoT devices increases. The queue length has a minor impact on the overall utility. It slightly reduces the utility for the greatest queue length and both task offloading schemes.

5. CONCLUSION

In this paper, the problem of task offloading in the industrial MEC environment is addressed. The novel auction-based task offloading scheme is proposed to meet the requirements in terms of utility and deadline constraints. The truthful double VCG-based auction mechanism provides incentives for MEC servers to perform task offloading and determines payment for each allocated task with deadline constraints. Extensive simulations are conducted to evaluate the performance of the proposed auction-based task offloading scheme. The results show superiority and improved efficiency compared to the classic greedy algorithm.

There are several potential future research directions. The benefits of a deadline-aware task offloading scheme can be observed from the users' perspective, as well. The proposed scheme can be extended to address potential penalties for failures. Task offloading among MEC servers can be introduced to improve resource utilization. Moreover, the energy consumption of the task offloading in the industrial MEC environment can also be a subject for future research.

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PART V

LOGISTICS CONCEPTS AND STRATEGIES

THE HISTORICAL DEVELOPMENT OF FREIGHT FORWARDING ASSOCIATIONS IN SERBIA

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Abstract: *The evolution of freight forwarding associations over the time has not been much explored, particularly in a specific geographic context. Instead, the research focus has traditionally been directed to identify, describe, and explain some current phenomena in society, often combined with the efforts to propose the solutions for certain challenges, or foresee the specific trends in the forthcoming period.*

Freight forwarding has a long and respectable tradition in Serbia. Still, the papers which explore the development of this economic activity in Serbia are notably missing. The presented research aims to reveal, consolidate, and systematize a scarce knowledge on evolution of our freight forwarding professional associations from 19th to 21st century. Their goals, activities and development could be related to the specific, and often turbulent economic, political, and social circumstances in Serbia, but also to the development of freight forwarding as an economic activity and a profession.

Keywords*: Freight forwarding, customs agents, professional associations, Serbia, tradition.*

1. INTRODUCTION

The freight forwarding, as an economic activity, has evolved over centuries. Some of the traditional freight forwarders from the end of XIX century have evolved from small family firms into the regional and global 3PL and 4PL providers and integrators, and the most powerful companies in the logistics industry in the XXI century (Pavlić and Grčić, 2013; Schramm, 2012).

During the long history, freight forwarders used to associate and make formal or informal groups, to protect common interests, reach common goals, and develop the profession. These associations have been developed from local communities to the national and regional associations and, finally, to the most important global association — FIATA (the International Federation of Freight Forwarders Associations), found in 1926, in Vienna.

The academic textbooks and scientific articles sometimes give a brief overview of the freight forwarding evolution, considering the evolution of logistics intermediaries in general, or freight forwarding industry in the specific geographical context (Schramm, 2012; Vahrenkamp, 2008), for particular transport modes, including intermodal transport (e.g. Anderson, 2009), or type of services /cargo (Emery, 1950). In some cases, the freight forwarding companies like Schenker proudly point out their long and respectable tradition (Matis and Stiefel, 2004), thus contributing to the scarce literature. After the Second World War, the development of freight forwarding as economic activity has been usually briefly described in the scholar books in former Yugoslavia, with the repeated focus on the period after 1945. Among the rare exemptions are the textbooks of Turina (1965) and, in the more contemporary literature, Stojanović, (2021).

However, the research on the history and evolution of freight forwarding associations are notably missing. The greatest scholars in former Yugoslavia had very rare and scanty descriptions of the freight forwarders' associations in these areas for the period before the Second World War (Turina, 1965; Zelenika, 1980). Hence, we explored how freight forwarders have been associated during the time, and how their associations and common activities have evolved to reach the common goals and to protect the professional interests in various political, economic, and social contexts in Serbia. The research covers the period from the late 19th century to the modern days. The presented findings reveal and systematize for the first time data on a long and respectable tradition of freight forwarding associations in Serbia and imply a significance of historical research in development of freight forwarding as a scientific discipline.

The paper is structured as follows. In the second Section, the research methodology is presented. The third Section describes thoroughly the characteristics of freight forwarding associations in different periods, their activities and evolution, within specific, and often turbulent economic, political, and social circumstances in Serbia. The fourth Section summarizes and highlight the main results and gives the final remarks.

2. METHODOLOGY

Due to the very scarce literature on the modes and characteristics of freight forwarding associations, their appearance, work, and historical development in Serbia, it was necessary not only to review the preceding scholar literature, but also to explore thoroughly previously unknown sources. The online national library information catalogue, COBISS platform, was used for a preliminary inquiry. The search was conducted mainly using the keywords associated with freight forwarding, such as “špedi”, “otprem”, “posredn”, "freight forward", and "spedition". A Digital library of previous legal regulations, textbooks and monographs published by The Administration for Joint Services of the Republic Bodies was also used. The selected sources (books, newspapers, scientific articles, etc.) were further explored in the most important libraries in the country — the National Library of Serbia in Belgrade and the Matica Srpska Library in Novi Sad. A need for primary historical sources initiated further fieldwork. Therefore, a thorough investigation of local and state archives was performed in the period December 2021 - March 2022. The primary sites of explorations were the Historical Archives of Belgrade, the Archives of Serbia and the Archives of Yugoslavia in Belgrade, the Historical Archives of Novi Sad, and the Archives of Vojvodina in Novi Sad. In the Historical Archives of Belgrade, some precious information regarding freight forwarders was found in the fond of the Belgrade Chamber of Commerce, including the important rulebooks and records from the annual assemblies of the Belgrade freight-forwarding associations. The research in the Archives of Serbia and the Archives of Yugoslavia was conducted in the fonds of Ministry of National Economy and Ministry of Trade and Industry, respectively. In the Historical archive of Novi Sad, the papers from the Association of merchants for the city and county of Novi Sad were inspected. In the Archives of Vojvodina, the stuff of the Ministry of Trade and Industry from the period between World Wars were examined. The periodicals were also used to fill in the gaps. They included the official newspaper such as *Srpske novine* (1895-1914), informational dailies such as *Politika* (1918-1941), a professional journal *„Špeditersko-carinski vjesnik"* (1921-1922). Due to the volume, complexity and dispersion of explored stuff, the research is not finished. Here are presented the main results, revealed, and processed from December 2021 till the end of March 2022.

3. FREIGHT FORWARDING ASSOCIATIONS IN SERBIA FROM 19TH TO 21ST CENTURY

3.1 The first records of a professional association

The first records on a formal freight forwarders association date back to the early 19th century. In 1821, the brothers Solar applied to the local government in Zemun to get the license for opening a customs warehouse and freight forwarding firm, named "Gondota". The same application was forwarded to the local freight forwarding association, a kind of „guild", for a professional opinion (IAB/10/2133). The answer of the guild's representative was negative, with a comprehensive explanation (IAB/10/2123). Finally, the town government ("Magistrat") refused the request in 1822, thus indicating the role of local freight forwarding association. This procedure was in the line with the common practice in the 19th century, that states still transfer certain regulatory rights to the local guilds, related to their economic activity. The town of Zemun was on the border between the Habsburg Monarchy and the Ottoman Empire and it played an important role in trade between two countries during 18th and 19th century. It could be expected that the similar local professional associations have been present in some other towns, with more freight forwarders and other logistic intermediaries during the 19th and at the beginning of the 20th century, or even earlier. Those were probably bigger towns, with developed international trade routes and locations near the borders, rivers, and railway stations. According to some sources, the main tasks of guilds in Serbia in 19th century was to protect their members from the unfair competition (Vučo, 1954). However, this business activity has been modernized and formally regulated at the end of 19th and the beginning of 20th century, in the Kingdom of Serbia.

3.2 From formal beginnings in the Kingdom of Serbia to the First World War

After liberation from the Ottoman Empire, and especially after gaining independence in 1878, the new Serbian state has adopted numerous laws related to the international trade, customs procedures, transport, and others, which directly impacted the freight forwarding profession. In 1895, the Ministry of Finance formally regulated the market of customs agents and freight forwarders, in the Rulebook on customs intermediaries (freight forwarders) (Ministarstvo finansija, 1895). According to the new rules, only individuals with a formal licence could be registered as freight forwarders and customs agents. Such decision has impacted to the market characteristics.

In the same year, freight forwarders, basically customs intermediaries, have immediately started with efforts to establish their own professional association (AS/MNP/1903/VI/53). They applied the request to the Ministry of National Economy, arguing in detail a recent development of freight forwarding activities in Serbia and an emerging need for a formal professional organization. In July of 1895, their request was approved, and the Freight Forwarding Guild (FFG) was found. Its first assembly was held in September of the same year. This is the earliest revealed record of a formal freight forwarding association in the Kingdom of Serbia. The FFG drew up the Rules of Procedure, the aim of which was to regulate the work of freight forwarders in the guild. Rules were accepted by the Ministry of National Economy in December of 1895, and this is the first known official written rulebook of freight forwarding association in Serbian history (AS/MNP/1903/VI/53). Research to date has shown that the guild activities continued at least until 1903.

The next known information comes almost a decade later. In 1911, the Executive Board of a freight forwarding association submitted a formal Opinion and remarks on the proposal of Customs law introduced by the Ministry of Finance to the National Assembly in October 1911. Opinion and remarks were directed to the deputies of the National Assembly, and it was printed as a book with 34 pages. The Executive Board presented detailed opinions, observations, and remarks, with thorough comments on many articles proposed in Customs law (Primedbe i mišljenje carinskih posrednika špeditera o projektu Carinskog zakona, 1911). Their overall conclusion was that the proposed law was harmful for the international trade and the state on a whole. Their well-argued and exhaustive comments, remarks and recommendations clearly demonstrate the main characteristics of the freight forwarding associations representatives. They were well-educated, experienced, and highly skilled professionals. They were fully aware of the practical implications and consequences of all articles in the proposed act.

The first known printed rules related to the same freight forwarding association were published in 1912 and were named the "Rules of the Association of trade-customs and railway-shipping intermediaries", thus indicating another name of the professional association, compared to the one from 1895. The main goals of the Association were (Pravila udruženja trgovačko-carinskih i železničko-brodarskih posrednika, 1912):

- To improve the work of the association and to cooperate with the Chamber of commerce in that sense;
- To establish the useful institutions for the own profession and the members;
- To propose the regulations for governing the relationships between the members;
- To cultivate the companionship and solidarity between the members in common affairs,
- To develop the communication and cooperation with the Chamber of commerce and other economic institutions, send the relevant reports etc.;
- To make records of all firms in the country registered for this economic activity;
- To protect the profession, and interest of association members, especially in the case of changes in laws and regulations concerning the profession, etc.

It could be noticed that the goals were well-established and matured. In the essence, they could be easily applied in the statutes of modern logistics and freight forwarding associations. Also, the printed Rulebook may indicate an increased need to make these rules more available to the members, and other interested institutions and professional organizations, but also to all freight forwarders in the country.

3.3 In the Kingdom of Yugoslavia: between two World Wars

After the First World War, a new-found state, the Kingdom of Serbs, Croats, and Slovenes, has created new opportunities for cooperation of freight forwarders in the Yugoslav area. In 1921, the Federation of Freight Forwarders of Yugoslavia was founded, with a headquarters in Zagreb. The members of this association were also dominantly coming from Zagreb, although there were firms from other cities located on the area of the current country Croatia, and in less extent from Serbia and Slovenia. For a while, the Federation has printed its herald, "Špeditersko-carinski vjesnik", with the first number already published in July of 1921, where Federation and its activities were mentioned on the first page (Anonimous, 1921, p. 1). Further available issues have also regularly brought the news about the Federation activities, but also many useful national and international news from the freight forwarding and freight transport world.

In the same year, a new Serbian organization was established in Belgrade, named the Association of Customs and Traffic Intermediaries — Freight Forwarders (CTIFF Association). Its rules were approved by the Chamber of Commerce in 1921, and by the Minister of Finance next year (Pravila udruženja carinsko-saobraćajnih posrednika – špeditera, 1922). The Ministry of Finance has also published a new rulebook for customs intermediaries (Pravilnik o carinskim posrednicima, 1921). The objectives of CTIFF Association were in many ways similar to the ones set up in 1912, with the main goals, as follows: to protect the interest of its members, to be an intermediary between the professionals and governmental institutions, like the Ministry of Finance, the General Directorate of Customs, etc., and to initiate the founding of useful institutions for freight forwarders. It should be emphasized that the sense for comradeship and solidarity seems to be amplified in the 1920s, according to the new rules. For instance, the updated rules clearly determined that the burials for the deceased members must be provided at the expense of the CTIFF Association, and that their families were entitled to three months of financial assistance.

The CTIFF Association was in 1932 transformed into the Association of Customs Intermediaries and Freight Forwarders for the City of Belgrade (CIFFB), which was recorded in the new Rulebook (Pravila udruženja carinskih posrednika i špeditera, 1932). It consisted of two sections — groups of members: the customs intermediaries and the freight forwarders. As stated by the report of the Executive Board of directors of the CIFFB Association, there were 58 firms — members in 1933, of which 30 customs intermediaries, 11 international transporters and 17 local freight forwarders (IAB/509/K84/16). As planned by the rulebook from 1932, the Support Fund for the Humanitarian Purposes of the Customs Intermediaries was established in 1935. The purpose of the fund was to assist exhausted, sick, and impoverished association members. The main source of money available to the fund was the property of the old Association of CTIFF, further supported by the regular monthly contributions from the members of the new association and with charitable contributions (Pravila potpornog fonda za humane ciljeve članova carinskih posrednika udruženja carinskih posrednika i špeditera za grad Beograd, 1935). The existence of this kind of foundation indicates the level of the mutual solidarity in the freight forwarding profession. It was particularly important in the circumstances where freight forwarders faced formidable consequences of the Great

Depression, which affected the reduction of trade turnover and depletion of their earnings. Apart from this fund, the association and both of its successive descendants have almost regularly allocated some charity funds for different needs of wider community, as evidenced in the minutes from their annual assemblies.

In 1936, the CIFFB Association was divided into the two separate associations — the freight forwarders (FFB), found on August 23rd, and the customs intermediaries (CIB), found on August 30th. The reasons were mostly related to the competition and conflicts of interests between these two groups of professionals. Split between customs intermediaries and freight forwarders even made it to the pages of the most influential daily in the country, „Politika” (Anonimous, 1936). The new associations almost immediately published their rules, and both were approved by the Chamber of Commerce on September 16th.

3.4 Under the occupation

The German attack on Belgrade in April 1941 marked the beginning of the World War II in Yugoslavia. After the quick defeat of Yugoslav army, the Kingdom of Yugoslavia was divided between the occupying forces and most of Serbia fell under German control. Under the new conditions, the entire Serbian economy was subjugated to the war aims of the Third Reich. The German companies had the privileged position in occupied Serbia. Both associations, FFB and CIB, have continued their activities in Belgrade during the war. They experienced a decreased need for export and import of goods, as well as a very challenging business and living environment under occupation. Still, they have continued with their work, including the humanitarian activities supported the members of the association and wider community in Serbia.

The racist ideology of Nazism has penetrated all pores of society and left its marks even on freight forwarding associations. New authorities have quickly launched an investigation into the owners of freight forwarding companies looking for the Jewish people among them (IAB/509/K84/33). The number of Jews listed in the records of the association's assemblies decreased significantly during the IIWW years.

3.5 The freight forwarding associations in the period of socialism

After 1945, the Yugoslav state underwent the radical ideological, political, social, and economic changes. During the Second World War and its aftermath, the Communist Party of Yugoslavia has come to the power, and was set about creating a new, socialist order. Accordingly, the measures of sequestration, nationalization and confiscation have followed attempts to reorganize and rebuild the Yugoslav economy. The Association of FFB and the Association of CIB have continued to exist formally until 1948. However, they were disbanded with the disappearance of private property and introduction of the new political and economic system. During the first post-war years, the monopoly over the international freight forwarding was granted to the state-owned companies, first „DETRANS“, and then „Minšped” and „Transjug“ (Turina, 1965). Since before 1952 the economy has been extremely centralized, the governmental professional freight forwarding associations were not exist in the country (Zelenika, 1980).

The introduction of workers self-management in 1952 and the liberalization of Yugoslav economy enabled the decomposition of monopoly in freight forwarding and the establishment of several new, specialized, state-owned freight forwarding companies.

Thus, a need arose for the establishment of professional freight forwarding organization, which would coordinate business, economic and legal relations between freight forwarders and other participants in the foreign trade and transport system. In 1952, the Community of International Freight Forwarding Companies was founded. One of its most important outcomes was the first General conditions of international freight forwarding work in the Federal People's Republic of Yugoslavia (Opšti uslovi rada međunarodne špedicije FNRJ), published in 1954 (Zelenika, 1980).

After the reorganization of foreign trade in 1954, the freight forwarding was recognized as a distinct economic activity in international trade. The Community was replaced with a new, International Freight Forwarding Section at the Federal Chamber of Foreign Trade. In the period from 1954 to 1990, several sections within the Chamber have gathered freight forwarders successively: International Freight Forwarding Section, at the Federal Chamber of Foreign Trade, the Commission for international freight forwarding and the Group for international forwarding. They have published several revisions of the General conditions concerned with freight forwarding economic activity: General conditions governing international forwarding agency services in Yugoslavia (1958), General business conditions of international freight forwarders of Yugoslavia (Opšti uslovi poslovanja međunarodnih špeditera Jugoslavije) (1970 and 1979).

Furthermore, the Subsection for International Freight Forwarding became a regular member of FIATA in 1959, on FIATA 6th congress held in Paris. Since then, the Yugoslav representatives were active participants in various FIATA's bodies and commissions. The crown achievement of Yugoslavia's participation in the FIATA was the organization of the 10th FIATA Congress in the city of Opatija, in August of 1967 (Zelenika, 1980).

In 1974, another very important association was found — the Association of Yugoslav Tariff Specialists. The main goals were (Sredić, 2005): to gather the workers of all transport modes and their inclusion into the market development, development and implementation of transport policy, the encouragement and the support of members in their professional development, the improvement of tariff system, the cooperation with the relevant governmental institutions, chambers and other national and international associations, the organization of professional symposiums, conferences, meetings, and similar manifestations, and publishing activity in the field of tariff and transport policy.

It has gathered primarily the freight forwarding experts who dealt with tariffs, especially railway tariffs, but also all other freight forwarders and logistic experts. This association has existed for more than three decades, including the first decade of 21st century. (Sredić, 2005). Vertically, it was a part of the European Association of Tariff Specialists and the International Association of Tariff Specialists. In Yugoslavia, they have actively cooperated with the Group for international freight forwarding within the Federal Chamber of Commerce, as well as with the national transport enterprises, governmental institutions, academics, etc.

These professionals have organized numerous professional meetings and symposiums throughout former Yugoslavia. They have also had a fruitful publishing work. UTJ has published several books — handbooks, professional glossaries of terms, etc., and a bulletin with the irregularly published issues. The Association of Yugoslav Tariff Specialists was active from 1974 for more than thirty years, including the challenging period of economic sanctions in 1990s and the first decade of 21st century.

3.6 The economic transition in 1990s and new business environment in the 21st century

The collapse of Yugoslav socialism marked the beginning of the economic transition to the capitalism. Although the period of transition began in the 1990s, most of the freight forwarding companies reached the 21st century without passing through the process of the privatization. During the 1990s, the business has been hampered by economic and political sanctions, which culminated with the NATO bombing of Serbia in 1999. Foreign companies have started with entering the market during this period, and this process were accelerated after the democratic changes in 2000. The market itself has become increasingly diversified, competitive, and based on capitalist principles. This was accompanied by the rapid development of digitalization and the growing interest in the environmental issues.

The Association of Yugoslav Tariff Specialists, and the professional group for international freight forwarding within the Chamber of commerce have witnessed all three political and economic periods, struggling their changing role for companies in the Serbian market.

In the 21st century, there is a variety of intermediaries and logistics providers in the market, who offer diversified services, or packages of services, from local market niches to global market coverage. The new business environment has also imposed a need for some changes and new solutions in associating freight forwarding and logistic companies. In the second decade of the 21st century, two associations are notable. The Serbian Chamber of Commerce continues to be a link between freight forwarders and FIATA, government institutions, and other professional groups and non-governmental bodies, but its role is not as strong as it was in the socialist period. The contemporary Group for freight forwarding and logistics within the Chamber of commerce was found in 2017. However, its members are mainly also the members of another main professional association, the National Association of Freight Forwarding Companies and Agents "Transport and Logistics", found in 2003 (Statut Nacionalne asocijacije “Transport i logistika”, 2016). Other logistics associations active in the last decades and worthy to be mentioned are the Serbian Logistics Association (SLA) and the Serbian Supply Chain Professionals’ Association. Both found their own niches in the market, organize the professionals' gatherings and meetings to exchange the experience between logistics professionals, including freight forwarders, provide the educational courses, etc. The former also publishes the professional journal "Transport i logistika".

4. FINAL REMARKS AND CONCLUSION

The presented research proves that the history of freight forwarders and their associations in Serbia is a long and fascinating one. It dates back centuries. However, the sources are scarce, and it is very likely that many precious documents are still missing, undiscovered, or even destroyed.

The Serbian turbulent history and the changes in social, economic, and political circumstances, the technological development and changing business environment have strongly impacted on freight forwarders common goals and activities. Thus, the professional associations and their characteristics have been changed during the time.

The earliest record on the freight forwarding association in Serbia is more than 200 years old and comes from Zemun, a city on the river Danube, where international trade was very developed in that time. Further research, that would explore more in-depth sources from 19th century and earlier periods, is necessary. It would be interesting to trace the records which evidence the foundation and work of this, or similar associations in other towns.

Before the IIWW, the professional associations have mostly gathered local professionals in the same city, or governmental region. The revealed documents evidenced that the very well-organized association have existed in Belgrade from the end of 19th and the beginning of the 20th century. The oldest printed professional rulebook is 110 years old. It could be expected that the similar professional associations were present in other cities with the significant number of freight forwarders and other logistic intermediaries. Further research is necessary to reveal more data. Furthermore, some sources revealed the attempts to develop a first national association in the Kingdom of Serbs, Croats, and Slovenes. The findings reveal that both local and national associations at the beginning of XX century were advanced and followed, or even pioneered similar trends in the most developed European countries, such as Switzerland and Germany (Zelenika, 1980).

After the Second World War and during the period of socialism, there was always only one, state-owned professional association, which gather all enterprises. The first such association was established in 1952, and soon transformed into a professional group within the Chamber of commerce. During its long history, the later has changed the name several times and has experienced different roles for companies in the Serbian market. Currently, there are several professional groups and associations which gather freight forwarding and logistics professionals in Serbia, with different roles in the market.

Not intentionally, several anniversaries in 2022 related to the freight forwarding associations in Serbia were revealed by this research. Such respectable history deserves attention and greater responsibility in preserving the tradition and nurturing the culture of remembrance of freight forwarders and their associations in Serbia. In general, the scientific literature on the freight forwarding history and evolution is scarce and deserves more attention and respect from both scholars and practitioners. The former should primarily contribute to the development of the scientific discipline, the latter rather to the keeping tradition and the culture of remembrance.

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DETERMINING COMPETENCIES REQUIRED FOR WORK IN THE LOGISTICS SECTOR

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Abtract: *This paper investigates the competencies required from the employees in the logistics sector in the Republic of Serbia. It first presents the results of similar research conducted in developed countries and then provides a detailed analysis of the competencies needed by logisticians to work in the Republic of Serbia. The basis for this analysis was provided through a survey among the respondents working in different areas and different positions in the area of logistics. Given the expected trends in logistics, in addition to the competencies required for work in the existing logistics management and supply chains, the competencies needed to work in the near future were also explored. The aim of this paper is to investigate and classify the knowledge and skills needed to work in logistics. The findings can be used to develop logistics education programs that will meet the demands of the economy in the Serbian market.*

Keywords: *logistics knowledge areas, logistics competency, education*

1. INTRODUCTION

By managing the flow of goods, logistics supports and connects the functioning of various economic sectors and is one of the key factors in the development of both individual companies and national economies. Technical and technological development, market globalization, customization of products and services and requirements for sustainability all contribute to the dynamic and turbulent character of modern business markets. In addition, company operations are affected by uncertainties and risks such as natural disasters, wars or epidemics. As a result, the already complex management of logistics and supply chains becomes even more complicated, a fact that is reflected in the knowledge and skills logistics professionals need for their work.

Logistics covers a wide range of areas such as warehousing, material handling, inventory management, transport management, etc., with each of these areas developing its own specific knowledge and standards. In addition, logistics as an interdisciplinary field based primarily on technology, economics and information science, combines different types of engineering knowledge with economic and managerial knowledge and skills. In other

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words, modern logistics is understood as an interdisciplinary concept and as such, interfaces with other business functions, as well as with other areas of engineering are abundant (Niine and Koppel, 2014). In the logistics system an individual, the initiator of all activities, and his/her knowledge and skills play a central role. On the one hand, logistics encompasses a large number of tasks and the specialist knowledge required for their implementation. On the other hand, it is interdisciplinary in nature and requires the general knowledge of other business areas necessary to harmonize the functioning of different parts of the chain. Bearing in mind these two aspects it is clear that a logistics expert - logistician, should have interdisciplinary and multidisciplinary knowledge, which more than ever, needs to be constantly supplemented.

Different jobs (such as transport, warehousing, customer service and procurement) and positions in logistics and supply chain management (operational, middle and strategic level) require different competencies, most often confirmed by appropriate qualifications. The qualifications are recognized as tangible outcomes of training and document an acquired skill and are vital to starting a professional career (Smith and Ridoutt, 2007). In addition to university degrees, various national and international certificates of competencies and occupational standards have been established as a confirmation of the professional qualifications and competencies of logisticians and these differ from each other to a certain extent.

The aim of this paper and research is to identify the knowledge and skills needed to work in the logistics sector, with a focus on the Serbian market. The remainder of this paper is organized as follows: Section 2 gives a brief overview of the literature discussing competencies in logistics. Section 3 describes the methodology for researching the competencies needed to work in the logistics sector in Serbia and discusses the results obtained in this study. The last part summarizes the conclusions and gives directions for future research.

2. LITERATURE REVIEW

Supply chains are becoming more complex, more extended, and more global every day, and for that reason logistics and supply chain management as well as the need for their adaptation to changes in business, require adequately educated professionals. According to early research on this topic, it has been determined that 25 scientific fields are involved in order to fully process logistics tasks (Muckelberg and Hille, 1997). This period is characterized by the differentiation of logisticians into two educational profiles: university degrees in business economics which should include the functions of market-oriented procurement, planning, management and implementation in the field of trade and administration; and, on the other hand, technical and logistical knowledge that covers the field of physical logistics and which is acquired at engineering faculties (Nikoličić, 1999). Today, in higher education of logistics, various curricular approaches exist from a "one-size-fits-all" style to a narrow specific focus (Niine and Koppel, 2014).

The demand for people in the field of logistics and supply chain management (SCM) is growing, and it is increasingly difficult to find qualified personnel for blue-collar work, white-collar work and knowledge work (Kotzab et al. 2018). The creation and implementation of educational programs, which in addition to traditional knowledge in the field of logistics and SCM include modern topics in this field (influenced by technical, technological and business changes), represents both an opportunity and a challenge for educational institutions to respond to economic demands. (Nikoličić et al. 2019).

Competencies in the field of logistics and SCM are the topics addressed by academics and professionals alike, which is confirmed by papers published in journals and presented at academic and professional conferences. Previous research has been conducted on limited geographical area, business focus, hierarchical level in management, etc. and all sought to identify relevant competencies for work in the logistics sector from their perspective, educational program and/or practice requirement. Here competency is understood as one's ability to combine knowledge, skills and attitude to show expected behavior when performing a professional task (Hofstra et al. 2020).

Establishing standards of logistics competencies can contribute to their harmonization, which is discussed in (Niine and Koppel, 2014). Based on six renowned international models of logistics competencies, an extended meta-model of knowledge areas needed by logistics professionals has been formed (20 knowledge areas, with each section containing 9-12 elements that should belong to logistician's training), with the idea to use it as a tool for benchmarking analysis of the existing curricula and programs of undergraduate studies in the field of logistics as well as for their further development. The model was tested by comparing curricula from five European universities, and it was concluded that differences between logistics curricula can be significant but that the key areas such as: transport planning, inventory, material handling and IT technologies, are generally present in all of them although to varying degrees.

The requirements for the competencies of logistics bachelor graduates in the Netherlands have been researched on the basis of current and expected trends and developments in logistics, and the research findings can be used to develop educational programs in logistics (Hofstra et al. 2020). A framework describing relevant competencies for logisticians developed in this research was also supplemented by findings from interviews with senior logistics professionals. As a result, relevant knowledge, skills (hard and soft) and attitudes have been determined for graduate logisticians, with each of the competency components explained in more detail. The research emphasizes that fundamentals of logistics such as knowledge on warehouse and inventory management, incoterms, customer service, trade law, forecasting, e-commerce and process optimization remain essential for young logisticians. In addition to this basic knowledge, logisticians need to: understand technological development and innovation and be able to work with new technologies and tools (digitalization, robotics, blockchain, internet of things, artificial intelligence, Big Data), gain general knowledge about business (e.g., finance, marketing and sales, operations management) and business processes. Regarding the skills of young logisticians, the use of foreign languages and MS Excel was especially emphasized, as well as personal attitudes: reliability, proactivity, curiosity and flexibility.

The requisite logistics and supply chain manager competencies have changed in recent decades owing to profound business transformations in the field, for example, the globalization of supply chains, continued outsourcing, and the widespread adoption of lean practices (Derwik et al. 2016). The academic literature discusses more than 280 skills and competencies related to the job profile of logistics and supply chain managers (Kotzab et al. 2018). Logistics and supply chain managers use business managerial, generic, and behavioral competencies in practice rather than supply chain management expertise, where the level of competency in practice extends beyond the sum of individual competencies (Derwik et al. 2016). The following have been identified as very important areas of functional knowledge required for supply chain management: communications/negotiations; computers/IT; general experience; logistics/supply chain management and skill areas: analytical, interpersonal, leadership and change management (Mangan and Christopher, 2005). Given the social development, companies must constantly change, which means a changing set of knowledge and skills needed to perform logistics and supply chain activities, the fact which is also reflected in the recommendations of the European Commission for Lifelong Learning (Kotzab et al. 2018).

3. COMPETENCIES REQUIRED FOR WORK IN THE LOGISTICS SECTOR IN THE REPUBLIC OF SERBIA

Given the continuous growth of the global logistics market over the past twenty years, experts expect that in the future there will be a significant demand for qualified logistics professionals, especially in management positions (Kotzab et al. 2018), which is further confirmed by the following facts:

- it is estimated that by 2030, the logistics sector will globally lack 16% of the skilled workforce in (3PL, 2019).
- In Serbia, employees in the area of logistics did not wait for their first job (50%) or waited up to six months (31%). In addition, in 2018, there were an average of 2.2 ads per day for management positions in the field of logistics (logistics managers, clerks, dispatchers), which further indicates the high demand for qualified logisticians (Kilibarda et al. 2019).

Research in this paper focuses on a skilled workforce in logistics, which implies a certain level of qualification that, through work experience, self-education or training, allows the acquisition and development of additional competencies needed in a rapidly changing logistics environment.

3.1 Methodology

In order to determine the competencies required for work in the logistics sector in the Republic of Serbia, a survey was conducted consisting of the following phases:

1. Based on the analysis of published papers, curricula and programs of bachelor's and master's studies in logistics as well as the experience of the authors of this paper, the areas of knowledge required for work in logistics have been identified. Development trends in the logistics sector were also taken into account.
2. Areas of knowledge (and skills) are divided into two basic groups: general-educational knowledge and technical-logistical knowledge, and the third group, which includes trends in logistics.
3. An online questionnaire was created which, in addition to general information about the respondent (work sector, position in the company, ...) contains a list of 63 questions related to the knowledge he/she needs to perform a particular job in the company. The questionnaire was first tested on a sample of 10 respondents who were asked to complete it and then also give their suggestions and comments. After that, minor corrections (explanations) were made and when its validity was confirmed, the questionnaire was sent to other respondents via a web survey (the

database of respondents engaged in various logistics jobs in various companies in Serbia was previously formed). The research was conducted in February 2022.

4. The obtained results were analysed and the main results are presented below:

It should be noted that this research is only a pilot study and will be extended to a wider sample of respondents.

3.2 Findings

The selected sample consisted of a total of 150 respondents and a total of 63 completed questionnaires were collected, which represents a response rate of 42%. Respondents are engaged in various jobs in logistics & supply chains, ranging from operational to managerial. Of the respondents who completed the questionnaire, about 49% are employed in manufacturing companies, 26% in the logistics sector (freight forwarders, carriers, PL), 14% in distribution and domestic transport and 11% in retail companies. When it comes to the field of logistics in which they work, warehousing and distribution (32%) and contract logistics (32%) are dominating. About 11% of respondents are engaged in just in warehousing, 9% each are engaged in procurement logistics and production logistics , while the remaining respondents are engaged in all logistics areas in the company. All respondents have higher education and from the aspect of their position in the company, 41.5% are engaged at the operational and middle level and 17% at the top level. The majority of respondents (about 69%) are employed in companies with over 250 employees, in companies with 50 to 249 employees, 23% of respondents are engaged, and in small companies (up to 49 employees) slightly less than 8%.

Regarding general educational knowledge (where knowledges are classified by need in performing the logistics work but does not belong to basic knowledge of logistics, such as foreign languages, mathematics, economics, etc .; this part of the survey contains a total of 5 questions), about 98% respondents (regardless of their position in the company) marked foreign languages as very important, but most of them (97%) had to learn further. Also, the field of information and communication systems and technologies was rated by 94% of respondents as a very important area for their work.

A broader set of areas covering physical logistics is classified as technical-logistical knowledge. This part of the questionnaire contains a total of 53 questions grouped into basic knowledge of logistics (such as knowledge related to: technologies and organization of various modes of transport, warehousing technologies and processes, forecasting, inventory management, freight forwarding, etc.), knowledge required for work with information technologies and systems (SAP, EDI, WMS, TMS, GPS, RFID, etc.), as well as social skills (such as: communication, teamwork, analytical reasoning and problem solving, etc.). In general, the most important knowledge for the work done by the respondents was the following: organizing and contracting road transport (94%), transport costs (91%), freight forwarding (91%), warehousing technologies (90%), modern information technology for identification, location and monitoring (90%) and project management and teamwork (93%). On the other hand, as knowledge that they do not need for their work or are not sure, the following are singled out: organizing and contracting railway transport (55%), water transport (57%), air transport (54%), city logistics (43%) , application of JIT tools (35%), kanbana (40%), lean principles (35%).

However, a more detailed analysis of the answers obtained in this way, primarily according to belonging to a certain sector and position in management, somewhat changes the conclusions about the knowledge needed to work in logistics. As an illustration, depending on the sector in which the respondents work, Figure 1 shows the summarized answers related to the two questions from this part of the questionnaire. As knowledges that are not needed or respondents are not sure, 35% of respondents higlighted the use of JIT tools, but in the manufacturing and retail sector over 80% of respondents pointed out this area as very important. For the second area in Figure 1, knowledge related to commissioning systems and technologies, 73% of respondents stated that it is important for their business, but in the retail sector all respondents (100%) rated this area as very important while in the distribution and domestic transport, 36% of respondents higlighted this area as important. For the same areas (questions) in Figure 2, the structure of answers according to the position in the company is presented. For 59% of respondents employed at the operational level, both areas are important for their work, while at the top level 91% of respondents emphasized the importance of knowledge related to order picking and technologies. This simple comparison has already pointed out the differences in the knowledge needed to work in logistics in different economic sectors and in different positions in the company, i.e. that in addition to basic knowledge of logistics, specific detailed knowledge within logistics areas is needed.

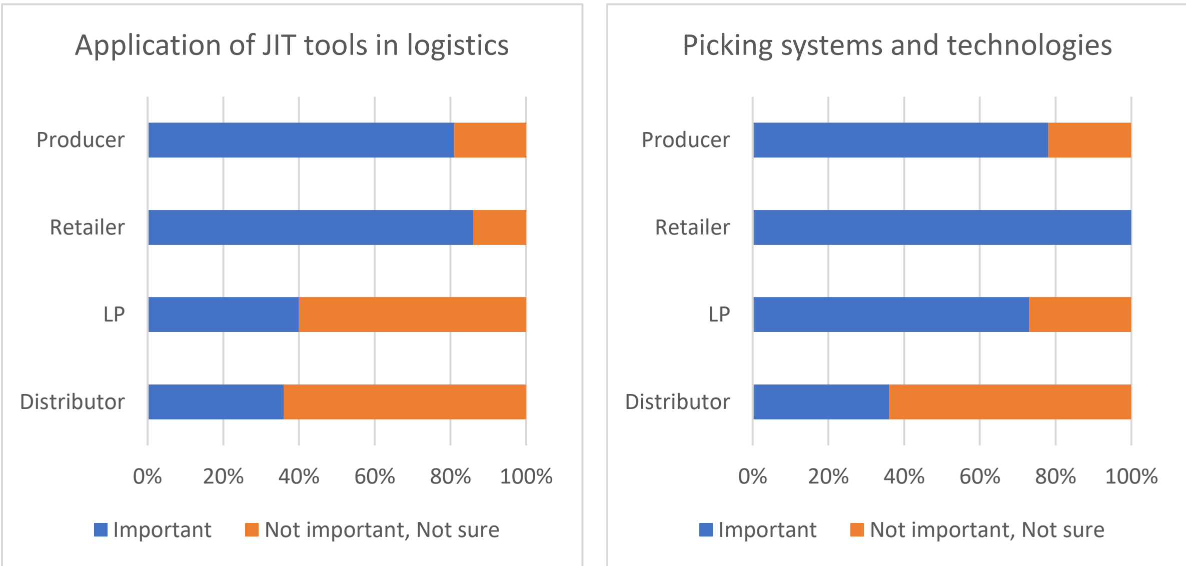

Figure 1. Importance of knowledge areas in different logistic sectors

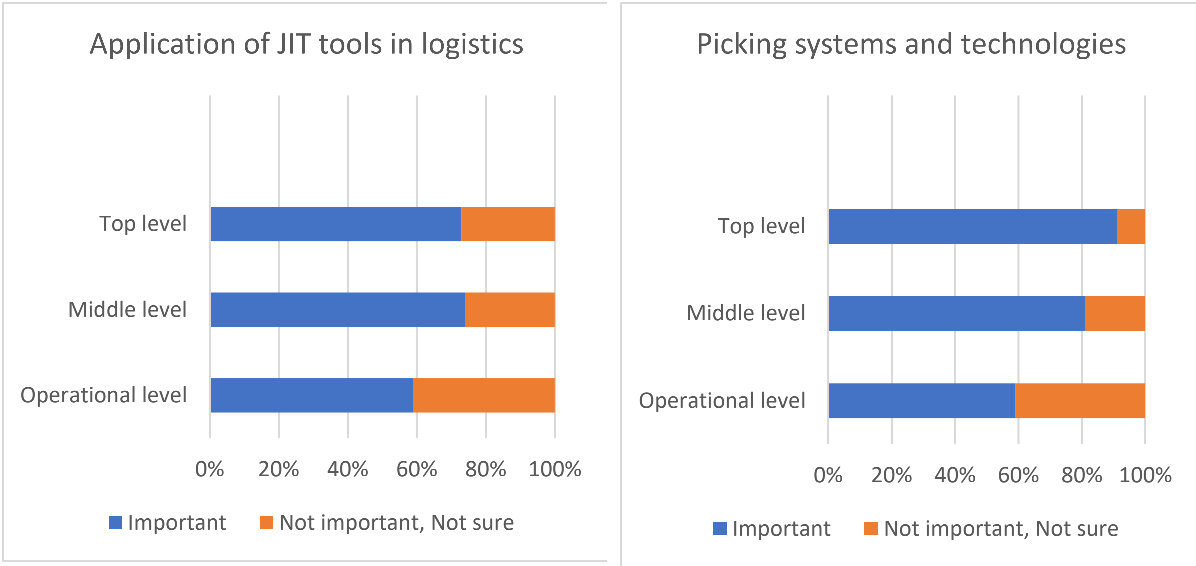

Figure 2. Importance of knowledge areas according to the position in the company

Trends in the field of logistics, which are already changing or will change jobs in the logistics sector in the near future, and thus the necessary knowledge of logistics, are highlighted in a special part of the questionnaire containing 5 questions. The answers of the respondents confirmed that the mentioned development trends in logistics are already happening in Serbia. The most pronounced changes are related to digitalization, ie about 81% of respondents did not say that they are already conducting partial or complete digitalization of business. On the other hand, the area where the least changes are expected is the application of data science and appropriate analytical tools in logistics, where 28% of respondents stated that they do not expect wider application.

Through their comments, the respondents especially emphasized the importance of good knowledge of foreign languages, work in Excel and more practical problems and practices during the study.

4. CONCLUSION

Depending on the functional area of logistics and the level of management, different qualifications and competencies are required for the professional performance of tasks in logistics and supply chains. Qualifications play a vital role at the beginning of a professional career and the studied academic literature suggests that undergraduate education should enable students to understand the "bigger picture" in logistics management and supply chains, which, depending on the field of logistics, mainly includes knowledge of transport management, warehousing and inventory management, customer service, trade law, forecasting, e-commerce, logistics IT systems and the relations between these functions. Technological, business and social trends and developments are reflected in the context and content of jobs in logistics, which makes it necessary to regularly update study programs in logistics and SCM. It is expected that in the future, logisticians will take on a more supervisory role and that knowledge and skills related to technology and innovations, IT, software, data science, analytical and problem-solving skills, accompanied by a proactive and flexible attitude and good communication skills, will become increasingly important. In other words, being a specialist and a generalist remains vital for graduate logisticians in the near future (Hofstra et al. 2020).

The competencies required from the employees in the logistics sector in the Republic of Serbia have shown similar results.

As the most important knowledge for the jobs they do, the respondents singled out the following skills: organizing and contracting road transport, transport costs, freight forwarding, warehousing technologies, modern information technology for identification, location and monitoring, project management and teamwork. Respondents particularly emphasized the importance of good knowledge of foreign languages and working in Excel. In addition, the results of the research confirmed that a logistician must be a generalist with detailed knowledge in certain areas. Such high demands for technical and economically - commercially oriented knowledge are difficult to connect within basic studies. As possible solutions for filling the gaps in the competencies of logisticians, the organization should be considered: modules within the basic studies in logistics, organization of specialist studies or seminars and courses for employees.

In a future work it is planned to increase the sample of respondents, in order to provide a basis for more reliable conclusions. As respondents work in different areas of logistics, it is very important to group them, and draw conclusions for each group about the relevance of knowledge and skills needed for their work in logistics. Drawing such conclusions is possible, among other things, only on the basis of a sufficiently large sample of respondents. For all groups of respondents, it is important to single out relevant identical knowledge (which makes the logistician a generalist) and relevant specialist knowledge for certain areas (which makes the logistician a detailist). As this research is primarily aimed at logisticians with university education. The results of the research can be used to create or improve a study program in logistics that would adequately respond to the needs of the Serbian economy.

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SUSTAINABLE TRANSPORTATION MODE SELECTION FROM THE FREIGHT FORWARDER'S PERSPECTIVE IN TRADING WITH WESTERN EU COUNTRIES

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Abstract: *The transportation mode selection problem is one of the most significant problems that logistics companies and freight forwarders face. The complexity of this problem is reflected in a large number of factors that affect the choice of an adequate mode of transport. In order to facilitate the decision-making process when choosing, the aim of this paper is to propose an approach for selecting sustainable transportation mode when trading with western EU countries using the Multi-Criteria Decision-Making (MCDM) methods, i.e., SWARA (Stepwise Weight Assessment Ratio Analysis) and MARCOS (Measurement Alternatives and Ranking according to Compromise Solution) methods. SWARA was used to determine the weights of the criteria, while MARCOS was used for the final ranking of the alternatives. In this paper, 9 criteria and 5 alternatives for the realization of transport from Serbia to Germany were observed. The results of the described methodology showed that road transport (via the Horgoš border crossing) proved to be the alternative with the best value, while road transport via the Batrovci border crossing proved to be the alternative with the worst value.*

Keywords*: mode selection, transport, sustainable logistics, SWARA, MARCOS*

1. INTRODUCTION

The organization of the international commodity flows is a complex task due to a large number of activities, participants, and documents. As this process requires knowledge of customs procedures, many companies leave this task to freight forwarders. One of the key problems that freight forwarders face on that occasion is the choice of transportation mode that will be used to realize the observed flow. The choice of an adequate transportation mode is influenced by a number of factors, such as the transportation time, costs, impact on the environment, infrastructure, retention at the border crossing, etc. Given that the awareness of environmental protection is at a high level in recent years, an increasing number of freight forwarders are striving for more environmentally friendly

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solutions for the realization of transport. On the other hand, in addition to this, freight forwarders can have an impact on the sustainability of a company's business, given that they are responsible for foreign and international trade with foreign company's partners. In addition to this impact, the choice of an adequate transportation mode can also have an impact on the company's competitiveness in terms of time and costs. For all previously mentioned reasons, freight forwarders pay great attention to solving the problem of choosing a transportation mode for the realization of commodity flows.

Given that the choice of an adequate transportation mode can have a crucial impact on the efficiency of a flow but also on the competitiveness of a company, the aim of this paper is to propose an approach based on Stepwise Weight Assessment Ratio Analysis-Measurement Alternatives and Ranking according to Compromise Solution (SWARA-MARCOS) methods for selecting a sustainable transportation mode from the perspective of freight forwarders in trade with western EU countries. The proposed model represents some kind of Decision Support System (DSS) tool for practitioners and also the basis for future research in the literature. In order to evaluate and select an appropriate transportation mode, evaluation criteria must be defined first. In this paper, 9 criteria were defined which were then used to evaluate 5 transportation modes. Since every criterion is not of the same importance, a SWARA method was used in order to determine the weight of each criterion. Obtained criteria weights were then used in the MARCOS method in order to determine the final ranking. The SWARA method is useful when there is a need to determine the weight of each criterion based on the experience and knowledge of the experts. In order to determine weights, experts' must first rank criteria from the most significant to the least significant. MARCOS method is based on defining the relationship between alternatives and reference values which are ideal and anti-ideal values. Next, utility functions of alternatives are determined as well as compromise ranking which is made in relation to ideal and anti-ideal values. The utility function is determined because it represents the position of alternative in relation to the ideal and anti-ideal solutions. The alternative that is closest to the ideal and at the same time furthest from the anti-ideal solution is the best according to this method.

The paper is organized as follows. After the introduction, a description of the problem is given as well as a review of the literature. In the next section of the paper, the methodology used in this paper is presented, which refers to the SWARA and MARCOS methods. The following section presents the results of the application of the described methodology. The last section provides concluding remarks as well as directions for future research.

2. PROBLEM DESCRIPTION AND LITERATURE REVIEW

Foreign trade is one of the most important branches of a country. On that occasion, two types of international trade can be distinguished, namely import and export. Numerous companies hire freight forwarders who have adequate knowledge and resources for organizing import-export commodity flows. After the engagement, the task of the freight forwarder is to determine the most efficient way of realizing that flow in order to keep the total costs as low as possible, with the shortest possible time of realization, in order to ensure the company's competitiveness in the market. When organizing a flow, one of the key things is to choose the appropriate transportation mode that will be used to perform the transport. On that occasion, it is necessary to take into account several elements that may affect the cost and time of realization of the flow. In addition to these impacts, in recent years more and more importance is given to the impact of a certain type of transportation mode on the environment, given that transport is one of the largest sources of pollution. Namely, although trucks account for less than 2% of the vehicles in Europe, they made up to 23% of the CO2 emissions from road transport in 2019. On the other side, the fastest-growing source of CO2 emissions from transport is vans, which now account for 13% of road transport carbon pollution in the EU (Transport Environment, 2022). For this reason, certain logistics companies are investing in new environmentally-friendly vehicles (such as vans that run on electricity). As the goal is to reduce the emission of harmful gases as well as the pollution caused by transport, this paper also defines the sustainability criteria that were used to evaluate the alternatives.

The problem of choosing a sustainable transportation mode has been recognized in the literature where there are papers that deal with this problem. Kundu et al. (2017) proposed a fuzzy multi-criteria group decision-making method based on ranking interval type-2 fuzzy variables for transportation mode selection. Hoen et al. (2014) determined the effect of carbon emission regulations on transport mode selection under stochastic demand, where they took into account emission costs as well. Also, Fulzele et al. (2019) proposed a model for the selection of transportation modes in the context of sustainable freight transportation. The authors in this paper used an integrated grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process and fuzzy multi-objective linear programming model. Zheng et al. (2016) in their paper observed both optimum pricing and order quantities, considering consumer demand and the selection of transportation modes by retailers, in terms of carbon emissions sensitivity and price sensitivity under the conditions of a cap-and-trade policy and uncertain market demand. A multi-objective optimization model for green supply chain network design for transportation mode selection was proposed in the paper by Gong et al. (2017). Namely, the proposed model considered both cost and environmental protection when the authors designed a multi-objective optimization model. In their paper, the authors considered four transportation modes, road, rail, air, and sea. Andrejić et al. (2013) in their paper estimated the energy efficiency of transport modes in Serbia by applying data envelopment analysis (DEA). Based on the literature review, it was determined that there are no papers that take the time of customs clearance as one of the criteria when evaluating different types of transportation modes. For that reason, in this paper, this criterion was used during the evaluation. Also, the goal was to propose a model for choosing a sustainable transportation mode but from the perspective of freight forwarders.

The aim of this paper was to select a sustainable transportation mode taking into account 9 criteria, of which 8 were taken from the literature and one was defined by the authors. On that occasion, the choice of mode from the perspective of freight forwarders in trade with western EU countries was observed, given that trade is very pronounced with western EU countries, which can be seen from the data presented in Table 1. Based on data it can be seen that the largest trade in the previous 7 months was realized with Germany, and for that reason, this country is considered as the destination country of the flow that was considered in this paper. For the realization of this flow, 5 alternatives were considered, of which 1 is realized by air transport, 2 by road, 1 by inland waterways, and 1 by rail.

The criteria used in this paper in order to rank alternatives are costs (C1), transportation time (C2), customs clearance time (C3), lead time (C4), transport energy consumption (C5), greenhouse gas emissions as CO_2 (C6), flexibility (C7), capacity (C8) and traffic congestion (C9).

Table 1. Foreign trade (Statistical office of the Republic of Serbia, 2022)

Period	Export (in mil €)				
	Germany	Italy	Bosnia and Herzegovina	Romania	Hungary
Aug-21	1718.6	1146	969.8	835.1	708.8
Sep-21	1971.3	1339	1120.2	930.6	800.9
Oct-21	2233.6	1524	1269.8	1020.6	903.6
Nov-21	2512.4	1696	1412.3	1111.3	1001.2
Dec-21	2743.3	1840	1562	1189	1088.9
Jan-22	243.7	148.1	108.9	-	92.6
Feb-22	516.2	315.3	257.7	162.4	193.4

The cost of the organization and the transport of goods on the route Serbia-Germany was observed under the costs. Transport time represents the time that elapses from the moment of dispatch of goods to the moment of delivery, not counting the time of detention of vehicles at the border crossing. Customs clearance time represents the time that elapses from the arrival of the vehicle at the border crossing until the end of all export customs procedures. Given that these times are different for each transportation mode, and that they can significantly affect the competitiveness of individual modes, the authors decided to take into account this criterion as well. In this paper lead time is defined as the sum of the average time the vehicle spends waiting in line at the border and dispatch of goods (the time that elapses from the moment of completion of export customs procedure to the moment of further dispatch of goods). Transport energy consumption and greenhouse gas emissions as CO_2 are criteria that are considered as a form of sustainability. Flexibility implies the possibility of adapting a certain type of transport to the new demands. Traffic congestion implies all congestion that is a consequence of a certain type of transport that can affect the increase in lead time, and for this reason, it was observed in this paper. The last criterion is the capacity of one vehicle in a certain type of transport, i.e., the amount of goods that can be transported by the vehicle during one delivery.

3. METHODOLOGY

In order to select the appropriate sustainable transportation mode, MARCOS method was used in this paper. In order to determine the weights of the observed criteria, a SWARA method was used (which were then used in the MARCOS method). The methodological steps of the application of these methods are presented below.

3.1. SWARA method

The procedure for the determination of weights by SWARA method includes the following steps (Radović and Stević, 2018; Pajić et al., 2021a):

Step 1 – All criteria should be sorted in descending order based on their significance evaluated by experts.

Step 2 – Starting from the second criterion, experts express the relative importance of criterion *j* in relation to the *j+1* criterion. This way the comparative importance of average value (S_j) is determined for each criterion.

Step 3 – Determine the coefficient k_j as follows:

$$k_j = \begin{cases} 1 & ,j = 1 \\ s_j + 1 & ,j > 1 \end{cases} \tag{1}$$

Step 4 – Determine the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1 & ,j = 1 \\ \frac{q_{j-1}}{k_j} & ,j > 1 \end{cases} \tag{2}$$

Step 5 – Calculate the weight values of criteria as follows:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{3}$$

where w_j represents the relative weight value of the criterion *j*.

3.2. MARCOS method

The procedure for the determination of the final ranking of variants by the MARCOS method includes the following steps (Stević et al., 2020):

Step 1: Formation of an initial decision-making matrix including *n* criteria and *m* alternatives.

Step 2: Formation of an extended initial matrix by defining the ideal (*AI*) and anti-ideal (*AAI*) solution.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \dots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{bmatrix} \end{array} \tag{4}$$

The anti-ideal solution (*AAI*) is the worst alternative while the ideal solution (*AI*) is an alternative with the best characteristics. Depending on the criteria nature, *AAI* and *AI* are determined using equations (5) and (6):

$$AAI = \min_i x_{ij} \text{ if j} \in \text{B and} \max_i x_{ij} \text{ if j} \in \text{C} \tag{5}$$

$$AI = \max_i x_{ij} \text{ if j} \in \text{B and} \min_i x_{ij} \text{ if j} \in \text{C} \tag{6}$$

where *B* represents benefit criteria while *C* represents cost criteria.

Step 3: Normalization of the extended initial matrix by applying equations (7) and (8):

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \text{ if j} \in \text{C} \tag{7}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \text{ if j} \in \text{B} \quad (8)$$

where elements x_{ij} and x_{ai} represent the elements of the matrix X.

Step 4: Determination of the weighted matrix V=$[v_{ij}]_{mxn}$ by multiplying the normalized matrix N with the weight coefficients of the criterion (9).

$$v_{ij}=n_{ij} \times w_j \quad (9)$$

Step 5: Calculation of the utility degree of alternatives K_i by applying equations (10) and (11) in relation to the anti-ideal and ideal solution.

$$K_i^- = \frac{S_i}{S_{aai}} \quad (10)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (11)$$

where S_i ($i=1, 2, \ldots, m$) represents the sum of the elements of the weighted matrix V, equation (12).

$$S_i = \sum_{i=1}^{n} V_{ij} \quad (12)$$

Step 6: Determination of the utility function of alternatives $f(K_i)$. The utility function is the compromise of the observed alternative in relation to the ideal and anti-ideal solution and is calculated by applying equation (13).

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (13)$$

where $f(K_i^-)$ represents the utility function in relation to the anti-ideal solution, while $f(K_i^+)$ represents the utility function in relation to the ideal solution, equations (14) and (15).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (14)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (15)$$

Step 7: Ranking the alternatives based on the values of utility functions where alternative with the highest value is the most desirable.

4. RESULTS

In order to determine the final ranking of alternatives, first, it is necessary to determine the weight of each of the observed criteria. Criteria were first ranked according to the importance by experts (from the most important to the least important), after which the other steps of the SWARA method were implemented. In the evaluation of the criteria, 10 experts were involved (including experts with years of experience in trading with western EU countries as well as professors). In order to get one value for every criterion, the geometric mean of the judgments was used (Pajić et al., 2021b). The results of the application of the SWARA method are presented in Table 2.

Table 2. Results of the SWARA method

Criteria	S_j	$K_j = S_j+1$	Q_j	w_j
Costs	-	1	1	0.162
Transportation time	0.03	1.03	0.971	0.157
Customs clearance time	0.07	1.07	0.907	0.147
Lead time	0.11	1.11	0.817	0.132
Transport energy consumption	0.32	1.32	0.619	0.100
Greenhouse gas emissions as CO2	0.05	1.05	0.590	0.096
Flexibility	0.17	1.17	0.504	0.082
Capacity	0.14	1.14	0.442	0.072
Traffic congestion	0.37	1.37	0.323	0.052
Σ			6.174	

Based on the results of Table 2, it can be concluded that costs and transportation time with a weight of 0.162 and 0.157 respectively are the two most significant criteria, while capacity and traffic congestion are the two least significant criteria with a weight of 0.072 and 0.052 respectively. After determining the weights of the criteria, the MARCOS method was applied in accordance with equations (4)-(15). In this paper, as mentioned, 5 alternatives were observed. The first alternative involves air transport (A1), the second road transport (via the border crossing Horgoš – A2), and the third also involves road transport (but in this case via the border crossing Batrovci – A3). The fourth alternative involves inland waterway transport (A4), while the last alternative involves rail transport (A5). The values of alternatives by criteria were determined as follows. The costs (C1) are defined on a scale from 1 to 5 in accordance with a certain mode of transport (where the costs of the realization of the flow, i.e., transport) were observed. For that reason, A1 has the highest value (thus it is the worst value). On the other hand, A2 and A4 have the best values according to this criterion, considering that the costs according to these alternatives are the lowest. The values of criterion C2 are determined on the basis of transport time from Belgrade to Frankfurt. The values of criteria C3 and C4, for alternatives A1, A2 and A3, were determined based on the data of the study which was provided by the Customs administration, which measured the time required for import-export procedures, where in this case the time required for export procedures were only observed (Customs Administration, 2021). The values for alternatives A4 and A5 were determined based on the assessment of experts in the field of inland waterway and railway transport. The values for criteria C5 and C6 were determined on the basis of data on transport energy consumption and greenhouse gas emissions as CO2 on the route Serbia-Germany (Ecotransit, 2022). Values for the last 3 criteria (C7-C9) were also determined on a scale of 1-5. In terms of flexibility (C7), alternatives A2 and A3 have the best values since they represent road transport, while alternative A4 has the worst value. The values of the capacity criterion (C8) are determined on the basis of data on the quantity of goods that can be transported by one vehicle in one delivery, where it was estimated that alternatives A4 and A5 have the best value and alternatives A2 and A3 have the worst. The values for the last criterion (traffic congestion – C9) are determined on the basis of congestion that can occur in a certain mode of transport (both during transport and customs clearance) where alternative A2 has the worst value while the A1 has the best (Table 3).

Table 3. An extended initial matrix

	C1	C2 (min)	C3 (min)	C4 (min)	C5 (megajoule)	C6	C7	C8	C9
type	min	min	min	min	min	min	max	max	min
AAI	5	12971	320	1450	1449419	107.14	2	1	5
A1	5	110	77	1370	1449419	107.14	4	3	1
A2	1	791	143	162	132408	9.55	5	1	5
A3	2	890	244	210	148979	10.74	5	1	4
A4	1	12971	320	1450	68347	4.9	2	5	2
A5	3	1055	300	1120	56500	2.51	3	5	3
AI	1	110	77	162	56500	2.51	5	5	1

After determining the extended initial matrix using equations (5) and (6), equations (7) and (8) were applied to determine the normalized matrix which was then used in the further steps of the MARCOS method (Table 4).

Table 4. Normalized matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
AAI	0.2	0.008	0.241	0.112	0.039	0.023	0.4	0.2	0.2
A1	0.2	1	1	0.118	0.039	0.023	0.8	0.6	1
A2	1	0.139	0.538	1	0.427	0.263	1	0.2	0.2
A3	0.5	0.124	0.316	0.771	0.379	0.234	1	0.2	0.25
A4	1	0.008	0.241	0.112	0.827	0.512	0.4	1	0.5
A5	0.333	0.104	0.257	0.145	1	1	0.6	1	0.333
AI	1	1	1	1	1	1	1	1	1
w_j	0.162	0.157	0.147	0.132	0.100	0.096	0.082	0.072	0.052

Values from the normalized decision-making matrix were then multiplied with the weight coefficients of the criteria, by applying equation (9), in order to determine the weighted normalized matrix. Obtained values are presented in Table 5.

Table 5. Weighted normalized matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
AAI	0.032	0.001	0.035	0.015	0.004	0.002	0.033	0.014	0.010
A1	0.032	0.157	0.147	0.016	0.004	0.002	0.065	0.043	0.052
A2	0.162	0.022	0.079	0.132	0.043	0.025	0.082	0.014	0.010
A3	0.081	0.019	0.046	0.102	0.038	0.022	0.082	0.014	0.013
A4	0.162	0.001	0.035	0.015	0.083	0.049	0.033	0.072	0.026
A5	0.054	0.016	0.038	0.019	0.100	0.096	0.049	0.072	0.017
AI	0.162	0.157	0.147	0.132	0.100	0.096	0.082	0.072	0.052

Afterward, values presented in Table 5, were used in equations (10)-(15) in order to determine the utility functions of each alternative as well as the final rank of the alternatives (Table 6).

Table 6. Final ranking

	Si	Ki-	Ki+	f(Ki-)	f(Ki+)	f(Ki)	Final rank
AAI	0.14747503						
A1	0.519	3.519	0.519	0.129	0.871	0.509	**2**
A2	0.570	3.863	0.570	0.129	0.871	0.559	**1**
A3	0.418	2.837	0.418	0.129	0.871	0.411	**5**
A4	0.476	3.226	0.476	0.129	0.871	0.467	**3**
A5	0.461	3.127	0.461	0.129	0.871	0.453	**4**
AI	1						

Final ranking of the alternatives can be shown as A2 > A1 > A4 > A5 > A3. Based on the results presented in Table 6, it can be concluded that A2 represents the best variant according to the MARCOS method.

5. CONCLUSION

A review of the literature established that there is a need for DSS tools regarding the observed problem. The importance of the correct choice of mode becomes even more important when the impact of a certain mode on the environment is included. For this reason, the subject of this research was to propose an approach for selecting sustainable transportation mode in trading with western EU countries, given that it was found that most of the exported quantity is with these countries. In order to rank the 5 observed alternatives using 9 criteria (costs, transportation time, customs clearance time, lead time, transport energy consumption, greenhouse gas emissions as CO_2, flexibility, capacity, and traffic congestion), SWARA and MARCOS methods were applied in this paper. Namely, as not all criteria are of equal importance, SWARA was applied to determine the weights of the criteria, which were then used in the MARCOS method for the final ranking of alternatives. The results of this paper showed that price and transportation time stood out as the two most significant criteria while capacity and traffic congestion stood out as the two least significant criteria. On the other hand, road transport (via the Horgoš border crossing) proved to be the alternative with the highest value, while road transport via the Batrovci border crossing proved to be the alternative with the worst value.

The proposed methodology of this research can be a good basis for people from practice when selecting sustainable transportation mode in trading with western EU countries. The application of the described methodology in trade with other countries and regions stands out as one of the directions for future research. In addition, the application of the proposed methodology for the selection of sustainable transportation mode for import also stands out as one of the directions of future research, given that in this paper only export from Serbia was observed. Also, the consideration of new alternatives, such as multimodal or intermodal transport when applying the proposed methodology, as well as developing new hybrid approaches suitable for solving these problems, also stand out as a direction for future research.

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OVERVIEW OF CRITERIA AND METHODS OF MACHINE LEARNING FOR SUPPLIER SELECTION

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Abstract: *The management and development of relationships with the supplier directly affect the efficiency and profitability of the company's operations. Modern information technologies enable the collection and processing of large amounts of data based on which new information can be created. Consequently, machine learning finds increasing applications in the supply chain. This paper provides an overview of the most common criteria and methods of machine learning in order to select the supplier. The application of machine learning and artificial intelligence can achieve significant optimization of the process in the supply chain.*

Keywords*: Supply Chain, Machine Learning, Supplier Selection, Criterion.*

1. INTRODUCTION

Supply chain management is becoming increasingly complex due to the greater competitiveness of companies in the market. In this problem, one of the most important tasks in supply chain management is the problem of supplier selection. Procurement management determines and reviews procurement strategies because the appropriate decision directly depends on the choice of the best supplier among the potential. In the older literature, general criteria for supplier selection can be observed, such as quality, price, delivery, and service. When looking at the newer literature, the authors' concern for the environment is noted, and they are increasingly observing the ecological criteria in selecting a green supplier. Characteristic methods for the supplier selection are the methods of multi-attribute and multi-criteria decision-making, the fuzzy logic, while lately the methods of machine learning are increasingly used.

The aim of this paper is to provide an overview of the criteria and methods of machine learning for selecting the supplier. The paper is organized, in addition to the introduction and conclusion, in four chapters. The second chapter provides an overview of the literature on the criteria and methods of the problem. The third chapter presents the most

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common criteria, and the fourth chapter describes the most common four machine learning methods used to select suppliers, listing the advantages and disadvantages of each. The last chapter contains the conclusion of this review and directions for future research.

2. LITERATURE REVIEW

The methodology for evaluating suppliers consists of conceptual and empirical approaches and modeling techniques (Jayant, 2018). The conceptual approach primarily emphasizes the strategic importance of supplier evaluation according to selected criteria. The empirical approach refers to determining the relative importance of the selected criteria for evaluating suppliers. Modeling techniques, i.e., models used for supplier evaluation, are numerous and can be found in the literature. Most models are used in the final process of selecting suppliers according to a set of defined criteria. In the continuation of the paper, a review of the literature on applied methods and criteria for supplier selection in various industries.

Plebankiewicz and Kubek (2015) conducted a study on the selected supplier of building materials based on AHP (Analytical Hierarchy Process) and FAHP (Fuzzy Analytic Hierarchy Process) methods. The authors took into account a large number of criteria that are subjective, difficult to measure, and in practice can lead to complexity in evaluating suppliers. To avoid problems in assessing the importance of criteria and supplier, the authors proposed the use of the mentioned methods of multi-criteria analysis. The authors classified ten sub-criteria into three groups of criteria: cost, quality, and technical characteristics. According to the defined sub-criteria, they evaluated ten suppliers and determined their ranking. Deshmukh and Sunnapwar (2019) proposed a model, based on the FAHP method, for the selection of a green supplier in the manufacturing industry. Scores of all criteria are given in the form of triangular fuzzy numbers. The FAHP method reduces the inaccuracy in calculating the relative weights assigned to different criteria. The authors evaluated three suppliers. Deshmukh and Vasudevan (2019) state that it is necessary to find the optimal path between industry and the environment. The initial phase is the adequate supplier selection who cares for the environment by reducing waste and using resources that do not pollute the environment. The authors presented the traditional and environmental criteria for evaluating suppliers in the production of plastic products in India. Eight main criteria and forty sub-criteria for supplier selection were used. The results of the model, based on the AHP and FAHP approaches, show that plastics companies focus on cost management, quality, and environmental production. Jayant (2018) proposed a model based on the AHP method for supplier selection in the automotive industry. The author states that procurement managers must periodically evaluate the performance of the supplier to cooperate with the supplier who meets their requirements. The author used four criteria such as quality, cost, flexibility, and reliability, and thirteen sub-criteria to evaluate three suppliers.

Pishchulov et al. (2019) proposed a model for determining the significance of criteria in supplier selection based on a combination of VAHP (Voting Analytic Hierarchy Process) and DEA (Data Envelopment Analysis) methods. The authors defined three groups of criteria for evaluating suppliers in the supply chain, which are: economic, environmental, and social criteria. The authors state that the VAHP method is a tool that helps in the supplier selection and comprehensive monitoring of the development of suppliers, in terms of continuation or termination of cooperation. Çalık (2020) has proposed a model for selecting a green supplier based on the components of Industry 4.0 by applying the integration of AHP and TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) methods with Pythagorean fuzzy numbers. The author used the Pythagorean FAHP method to determine the weights of the criteria, and the Pythagorean fuzzy TOPSIS method to determine the best supplier. Five suppliers were evaluated in the model.

Jain et al. (2020) created a model based on the Fuzzy Interface System (FIS) and the fuzzy MCDM (Multi-Criteria Decision-Making) approach to assess the sustainability performance of suppliers in the iron and steel industry in India. They used three dimensions of sustainability: economic, environmental, and social. To determine the ranking index of the four suppliers, they created three different FIS models for each dimension of sustainability using the FAHP and fuzzy TOPSIS methods. Omair et al. (2021) proposed a model based on a combined approach of the AHP method and the FIS supplier evaluation system. The AHP method was used to assess the importance of the criteria, and the FIS system was used to determine the ranking index of seven suppliers. Jain and Singh (2019) proposed a model based on the FIS system for supplier selection in the iron and steel industry. The authors used a FIS system that includes a Kano fuzzy model to group the criteria in evaluating supplier performance and selecting the best one. The advantage of the Kano fuzzy model is the identification of the most important sustainability criteria because it makes it easier for decision makers to observe a smaller number of criteria. They defined three groups of criteria for the evaluation of seven suppliers, which are: economic, environmental, and social criteria. Fallahpour et al. (2021) created a hyper-hybrid model based on FDEMATEL (Fuzzy DEcision-MAking Trial and Evaluation Laboratory), FBWM (Fuzzy Best Worst Method), FANP (Fuzzy Analytical Network Process), and FIS system for supplier selection in the palm industry oils in Malaysia. The authors divided 30 criteria for evaluating supplier performance into three groups: general, sustainable, and resilient. Garcia et al. (2018) developed a model based on two evaluation methods for supplier selection. Evaluation methods are the Factor weighting method (FWM) and the FIS system. The results showed the superiority of the FIS system as it allows for better management of inaccuracies and uncertainties in supplier evaluation. The authors used product, price, and delivery criteria to evaluate ten suppliers.

Abdulla et al. (2019) presented an integrated approach to machine learning methods and AHP methods for assessing and selecting the best supplier. The complexity of the supplier selection process is increased by observing a large number of criteria and suppliers. The authors used decision tree algorithms to evaluate the most important criteria, instead of applying the AHP method to a set of all criteria. The results showed that decision tree algorithms can successfully determine the most important subset of supplier selection criteria, thus reducing the complexity of applying the AHP method. Hosseini and Barker (2016) used the Bayesian network to determine the causal relationship between the criteria by which suppliers are evaluated and selected. Primary criteria, green criteria, and resistance criteria were observed. The process of selecting a supplier does not end with finding the desired supplier, but it is a continuous process that aims to monitor and replace existing suppliers with new ones to achieve greater benefits in business. Modern technologies collect, transmit and store information that enables real-time decision-making. It is necessary to identify an effective method for assessing suppliers in today's information society in which everything is shaped by information. In the age of Industry

4.0, efficient results are achieved by processing all collected data using machine learning methods that can analyze large and different datasets (Kiran et al., 2021).

3. CRITERIA FOR SUPPLIER SELECTION

Selected one of several potential suppliers is a strategic decision of the company. There are various criteria in the literature that relates to the performance of the supplier and that the authors present as a rationale in deciding the selection of supplier. Each author proposes several criteria that are evaluated using certain methods and whose analysis results show the importance of the criteria for assessing potential suppliers (Dickson, 1996). Based on the literature review, the criteria and sub-criteria are presented, which are shown in Table 1.

Table 1. Criteria and sub-criteria in the selection of supplier

Criteria	Sub-criteria	References
Quality of delivery	Quality of goods; Delivery timed accuracy; Flexibility; Assortment; Packaging and securing of goods	Taherdoost and Brard, 2019; Fallahpour et al., 2017; Wang et al., 2017; Tirkolaee et al., 2019; Dickson, 1996
Price	The unit price of goods; Terms of payment; Tax; Discount; Costs	Taherdoost and Brard, 2019; Fallahpour et al., 2017; Cengiz et al., 2017; Chen et al., 2018; Dickson, 1996
Location	Geographical distance; Traffic infrastructure; Road speed; Type of transport; Transport conditions and administration	Taherdoost and Brard, 2019; Fallahpour et al., 2017; Cengiz et al., 2017; Dickson, 1996
Reputation	Reliability; Organization; Automation; Financial stability; Environmental and social responsibility	Taherdoost and Brard, 2019; Fallahpour et al., 2017; Wang et al., 2017; Tirkolaee et al., 2019; Chen et al., 2019; Dickson, 1996
Professionalism	Servicing; Providing additional services; Application of information and communication technologies; Responding to disturbance conditions; Compliance with business confidentiality agreements	Taherdoost and Brard, 2019; Cengiz et al., 2017; Dickson, 1996

Delivery can be considered quality when the right goods are delivered, the right quality at the right time. To ensure quality delivery, the supplier must allow flexibility in delivery, a wide assortment of goods, adequate packaging, and security of goods. Flexibility is the adaptability of the supplier in the price of goods, delivery costs, delivery times, etc. Assortment implies the ability of the supplier to provide quality goods to the customer in the right quantity, model, shape, color, etc. To preserve the original quality of the goods, it is necessary to pack the goods and ensure that there is no damage during handling and transport.

Price for the buyer is a very important criterion in selecting the best supplier. The price of the service is influenced by several factors, such as the unit price of goods, payment terms, taxes, discounts, and costs. The unit price of goods means the cost of the product itself. Certain payment terms may facilitate the payment of goods to the supplier by the buyer. Terms of payment for goods are the possibility of cash payment, the possibility of a payment in installments, the possibility of a payment in exchange, and the possibility of a refund. The price of the tax, which affects the price of the provided service, depends on the type and price of the goods, the location of the supplier, etc. The costs include logistics and transport costs, whose reduction contributes to the cost saving of the company or customer.

Location is a criterion that influences the selection of a supplier and can be described by several sub-criteria that can influence the supplier selection process. The first sub-criterion is the geographical distance of the supplier from the customer, which does not have to be a problem if the traffic infrastructure is good in terms of passability and speed of roads. The type of transport implies the possibility of using several types of transport and alternative routes. Increasing attention is being paid to the use of environmentally efficient transport and vehicles. Green transport means that carriers minimize environmental pollution during transport by using environmentally friendly vehicles and green fuels and respecting Euro standards that primarily apply to trucks. Administration refers to customs procedures whose complexity depends on the country in which the supplier is located.

Reputation represents the reputation and position of the supplier in the market that depends on the following six sub-criteria: reliability, organization, automation, financial stability, environmental and social responsibility. The reliability of the supplier is observed based on its work performance, i.e. customer feedback and cooperation with business partners. Organization means efficient decision-making and problem solving. To achieve the most efficient realization of business, it seeks to automate business processes by applying modern technologies. Financial stability refers to the liquidity of suppliers. Environmental and social responsibility means that the supplier uses environmental solutions and smart technologies in the production and transport of goods to minimize emissions and preserve the environment.

Professionalism implies certain competencies or skills of suppliers with which they will consistently fulfill the promised quality. The professionalism of a supplier can be described through the following sub-criteria: servicing, providing additional services, application of information and communication technologies, responding to disturbance conditions, and compliance with confidentiality agreements. The service of servicing goods includes the repair of goods or the possibility of returning damaged goods. The provision of additional services refers to the possibility of processing goods to exceed customer expectations. The technological ability of suppliers is reflected in the use of new technologies and technical resources in business processes. The application of information and communication technologies enables modern business, easy communication, and a simple exchange of information between the supplier and the customer. The use of modern technologies enables monitoring of the realization and visibility of all processes in the supply chain and the possibility of a quick response in the event of a disturbance. Mutual trust and respect for contracts are key to successful long-term cooperation.

Figure 1 shows the procedure for selecting a supplier. The first step is to identify the criteria, and then determine the weight of the criteria. After that, potential suppliers are identified as alternative selections. The next step is to identify methods and develop models in order to select supplier.

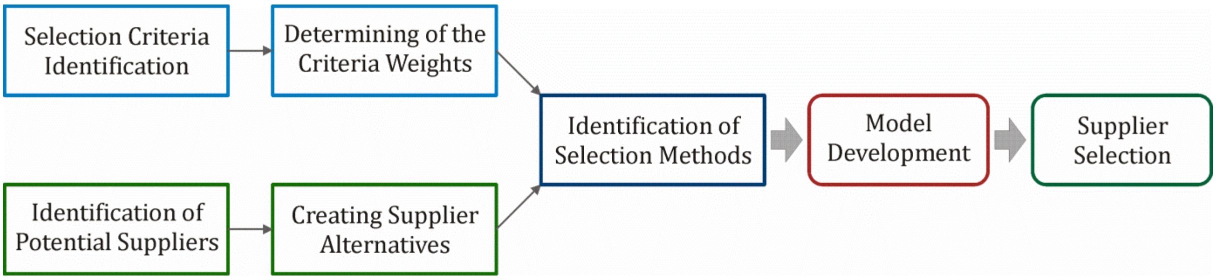

Figure 1. Supplier selection Procedure

4. METHODS FOR SUPPLIER SELECTION

The most common methods in the scientific literature used to select suppliers are (Pal et al., 2013): Methods for prequalification of supplier (e.g. Categorical Methods, DEA, Cluster Analysis), Multi-Attribute Decision Making (e.g. AHP, ANP, TOPSIS, MAUT, Outranking Methods), Mathematical Programming Models (e.g. Linear Programming – LP, Multi-Objective Linear Programming – MOLP, Goal Programming), Artificial Intelligence Methods (e.g. Case Based Reasoning, Artificial Neural Network), Fuzzy logic approaches and combined approaches (e.g. AHP+TOPSIS, AHP+MOLP, MAUT+LP). However, a recent review of the literature noted the use of machine learning methods to select suppliers. Machine learning methods enable work with inaccurate and uncertain data, qualitative and quantitative attributes, and large datasets for model development. Companies use modern technologies that collect large amounts of data in all supply chain processes. Consequently, the use of machine learning methods to make decisions in the supply chain is becoming common practice. The most common methods of machine learning for making decisions about selecting the supplier are (Sepehri, 2020):

- Neural network,
- Bayesian network,
- Support vector machine,
- Decision tree and
- Combined methods.

Neural networks are described as mathematical models for processing information. The development of models based on artificial neural network methods to some extent mimics the way the human brain functions. The processing of information in an artificial neural network is carried out in its elements called neurons. Neural networks are grouped into several layers: the input layer, one or more hidden layers, and the output layer. The input layer consists of nodes called dendrites that correspond to the input variable, and the output layer consists of nodes called axons that correspond to the output variable. The calculation process is performed in the hidden and output layers. That is, hidden nodes receive data from the input layer, combine it with a coefficient or weight that amplifies or minimizes input, and then add the resulting products. Finally, the activation function is applied to the sum to determine the amount of influence of the signal, which traveled through the network, on the final result (Bousqaoui et al., 2017). Artificial neural networks enable learning from experience, generating and observing important characteristics in input data that often contain irrelevant information. Neural networks can be used for problems of recognition, mapping of input data to output data, grouping, classification, and solving optimization tasks (Teodorović and Šelmić, 2019).

Bayesian networks are a graphical model that helps to judge the presence of uncertainty. That is, Bayesian networks graphically describe networks of patterns and consequences using a set of nodes and a set of causal relationships between variables. The causal relationship between variables can be expressed as a conditional probability. Variables can be based on historical data, expertise, and their combination. Bayesian networks are represented by directed acyclic graphs. In relation to neural networks, there are no hidden nodes in Bayesian network models. Graph nodes represent a set of random variables, and each random variable is an uncertain event. In general, random variables can be discrete or continuous. This method can process both qualitative and quantitative variables (Hosseini and Barker, 2016; Dohale et al., 2021).

The method of support vectors is based on finding a hyperplane that separates data according to different classes to maximize the margin between classes. The margin represents the width of the distance between the two classes that need to be maximized. Supporting vectors represent the data closest to the margin and contribute the most to successful classification. Also, this method based on hyperplane creates a model that predicts which of the classes to the new instance belongs. The idea of this method is that in a vector space using hyperplanes, all data from the same class are on the same side of the plane. The method of supporting vectors is a method of supervised learning that is used for classification and regression analysis (Vujinović, 2019; Nedeljković, 2015).

Decision trees are graphs of decisions and their possible consequences. Each node in the decision tree contains a question that relates to a specific attribute. According to the answer to the question asked, i.e. according to the value of a certain attribute for each individual sample, the set of defined nodes is divided into two subsets and forms two new nodes. The task of this method is to find the optimal question based on which the separation of nodes will be carried out by going through a set of potential questions to make the nodes cleaner after each question asked. The purity of a particular node is expressed in the dominance of one of the classes in the set. The criterion for cessation of branching may be the achievement of an absolutely clean node or a limitation in terms of the maximum number of samples in the last node or the maximum depth of the tree. Nodes that do not have subsets are called leaf nodes. Decision trees are used to develop classification and regression models. In the regression model, the value of the output variable usually represents the average value of the samples in the last node, and in the classification models, it is usually determined as the class that dominates among the samples in the last node (Nosek et al., 2020).

These four methods of machine learning for supplier selection have some advantages and disadvantages among themselves. In Table 2, the first column on the left represents the name of the method, the second column the advantages of the method, and the third column shows the disadvantages.

Table 2. Advantages and disadvantages of four machine learning methods (Du et al., 2019; Ray, 2019)

Method name	Advantages	Disadvantages
Neural network	Nonlinear adjustment; Simple learning rules; Strong robustness; Independent learning; Spreading the error backward; Good parallelism	Inability to judge the process; Unsuitable for a small dataset; Sensitive to initial values
Bayesian network	Good for small datasets; Applicable to multi-classification; Easy implementation; Working with continuous and discrete data	Requiring an assumption for the uncertainty condition leads to less accuracy; Poor performance classification
Support vector machine	Suitable for nonlinear classification; Applicable to classification and regression problems; Easy to understand; Minor errors in generalization	Sensitive to functions and parameters; Performance declines with a large dataset; Long training time
Decision tree	Easy calculation and handling of missing value attributes; Evaluates different attribute characteristics; Strong interpretability	Problem overfitting; Unstable tree size control; Local optimal solution

5. CONCLUSION

Based on the literature review, it can be concluded that the most common criteria for evaluation and supplier selection are quality of delivery, price, geographical distance, reputation, and professionalism. In the literature, in addition to traditional methods for selecting suppliers, machine learning methods are increasingly used. Modern technologies collect large amounts of data that can be processed in an “intelligent” manner by methods of machine learning and therefore make business decisions. Each method has disadvantages and advantages, in terms of compatibility in applying to a particular dataset and problems.

In future research, a combined model based on traditional and machine learning methods can be created to evaluate and select criteria and suppliers in the supply chain. Machine learning enables the processing of large amounts of data and contributes to the decision-making process.

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PREDICTION OF DAILY DEMAND FOR GOODS USING WEKA SOFTWARE TOOL

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Abstract: *Predicting the demand for goods is an important task that directly affects procurement planning, inventory management and sales. Companies need to make an accurate forecast of demand for goods in order to successfully respond to customer requests and have an adequate range and quantity of stock goods. Based on the collected historical data and the application of predictive analysis methods in data mining software tools, companies can predict the demand for goods. In this paper, the prediction of the daily demand of five products was performed using supervised machine learning in the Weka software tool. The following features were selected as independent attributes that affect the quantity of goods demanded: product, day, month and day of the week. The datasets on which machine learning models were trained and tested covers the period from January 2018 to September 2020. Research shows that supervised machine learning is an effective method for predicting the demand for goods. The best results in predicting the demand for selected products were shown by the Decision Table and Random Forest algorithms.*

Keywords*: logistics, machine learning, prediction, demand*

1. INTRODUCTION

Predicting demand for goods is an important part of the supply chain management process (Qasem, 2019). Forecasts affect decision making throughout the supply chain from the operational to the strategic level, such as the procurement of raw materials, goods, assets, transport organization, deployment and employment of workers, etc. The prediction of daily demand for goods is important in organization, planning and scheduling of activities in logistics processes because it enables the right time to meet customer requirements, reduce costs and improve the efficiency of realization of activities in the supply chain. Machine learning is a technique that can be used for different types of predictions, one of which is the prediction of demand for goods. Specialized tools for

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creating and using prediction models can facilitate operational and strategic planning for logistics companies.

In literature, there are numerous papers in which researchers used machine learning algorithms for different types of predictions in the field of logistics. Qasem (2019) has implemented a PART strategy to predict the daily demand of the Brazilian logistics company's products. The results showed that PART classifiers with high accuracy gave a prediction of daily product demand. Alnahhal et al. (2021) dealt with the dynamic prediction of delivery times in logistics companies to optimize the consolidation of goods. Consolidation of goods reduces costs, but can increase delivery time. Kilimci et al. (2019) have integrated 11 different models that include multiple time series algorithms, the support vector method for regression analysis, and the deep learning method to predict demand. The authors of this study concluded that by inclusion of several different training algorithms, other than time series models, they improve the performance of models for predicting demand. Janković et al. (2020) conducted a descriptive and predictive analysis in the case study of foreign trade in food products for the Republic of Serbia. The authors of this research used supervised machine learning to predict the volume and structure of imports and exports in the food industry by using Weka software tool. They concluded that descriptive analysis and visualization of dependent and independent variable ratios on the initial dataset makes predictive analysis more efficient.

The aim of this paper is to obtain a prediction of the daily demand of five products by applying the methods of predictive analysis using Weka software tool. The data was obtained from the company Milšped, which is one of the leading logistics providers operating in Serbia. The basic services provided by Milšped are warehousing and transport services. The data is divided into two parts, so that about 2/3 of the available instances are a dataset for model training, and about 1/3 of the instances is a dataset for model testing. The paper presents the results of algorithms with the best performance, namely Decision Table and Random Forest. After training the model, model testing was conducted by predicting on the test dataset, and the projected demand values were compared to the actual demand values.

The paper is organized in three sections, in addition to the introduction and conclusion. The second section of the paper describes the machine learning method and algorithms that produced the best results in this study. The third section contains a brief description of the case study that is a part of this research. In the fourth section, the results of the best performance algorithms are presented and analyzed. The last section contains the conclusions of this case study and the directions of future research.

2. MACHINE LEARNING METHOD

Machine learning is a branch of artificial intelligence and a method of data analysis based on the idea that a computer system can automate learning from historical data and thus improve its work. It is applied to detect invisible patterns, market trends, hidden correlations, and other useful information for a particular aspect of data usage. Machine learning uses algorithms that allow a predictive model to learn based on historical data and predict the future values of the observed variable. Today, this method is most commonly used on large data sets. Machine learning consists of three phases: model training phase, model testing phase and prediction phase. Types of machine learning are supervised learning, unsupervised learning and reinforcement learning. Supervised learning applies over label data for prediction the target variable. Unsupervised learning applies to a set of unlabeled data to detect hidden patterns in the data. Reinforcement learning uses both labeled and unlabeled data for training, i.e. model learns by method of attempts and errors, while each action carries a reward or punishment. The prediction phase in machine learning involves applying of the best trained prediction model on a new unlabeled dataset and obtaining new data that represent the prediction of a specific target variable (Salkuti, 2020).

In this study, supervised machine learning was applied on the available data set with the aim of obtaining a prediction of the target variable. First, the model was trained on the labeled training dataset, and then using the trained model, a prediction of the target variable over the testing dataset has been made. After the model testing, a comparative analysis of the values of actual and projected demand quantities of five products was performed, according to the two algorithms that gave the best performance of the predictive models. The observed performances are (Folorunsho, 2013):

- Mean absolute error - represents the average of the absolute values of the differences between the actual and projected value of the target variable, i.e. it is the average prediction error.

$$Mean - absolute\ error = \frac{|p_1 - a_1| + \cdots + |p_n - a_n|}{n} \quad (1)$$

- Square root of mean square error - represents the square root of the mean square of the difference between each projected value and the corresponding actual value of the target variable.

$$Root\ mean - squared\ error = \sqrt{\frac{(p_1 - a_1)^2 + \cdots + (p_n - a_n)^2}{n}} \quad (2)$$

- Relative absolute error - represents the ratio of the total absolute error of the projected values in relation to the actual values of the target variable and the total absolute deviation of the actual values from their average value. It is expressed as a percentage.

$$Relative - absolute\ error = \frac{|p_1 - a_1| + \cdots + |p_n - a_n|}{|a_1 - \bar{a}| + \cdots + |a_n - \bar{a}|} \quad (3)$$

- Root relative square error - represents the square root of the ratio of total square error of projected values in relation to the actual values of the target variable and the sum of squares of deviations of real values from their average value. It is expressed as a percentage.

$$Root\ relative - squared\ error = \sqrt{\frac{(p_1 - a_1)^2 + \cdots + (p_n - a_n)^2}{(a_1 - \bar{a})^2 + \cdots + (a_n - \bar{a})^2}} \quad (4)$$

- Correlation coefficient - represents the degree of difference between actual and projected values of the target variable, i.e. the strength of their mutual connection. The higher the value of the correlation coefficient, the stronger the relationship.

$$Correlation\ coefficient = \frac{S_{PA}}{\sqrt{S_P S_A}} \tag{5}$$

$$S_{PA} = \frac{\sum_{i=1}^{n}(p_i-\bar{p})(a_i-\bar{a})}{n-1},\ S_P = \frac{\sum_{i=1}^{n}(p_i-\bar{p})^2}{n-1},\ S_A = \frac{\sum_{i=1}^{n}(a_i-\bar{a})^2}{n-1} \tag{6}$$

Where:

- n - the total number of instances for testing,
- $p_1,\ldots, p_n$ - the projected values on test instances,
- $a_1,\ldots, a_n$ - actual values,
- $\bar{p}$ - mean projected values,
- $\bar{a}$ - mean actual values.

This study uses the specialized software tool Weka (Waikato Environment for Knowledge Analysis), which is open source and developed at the University of Waikato in New Zealand. Weka is a simple tool for use and provides the ability to perform the following data mining tasks: data preparation, classification, regression analysis, clustering, association rule learning, selection of relevant attributes, and data visualization (Witten and Frank, 2005). The files that can be loaded in software tool Weka are text files format ARFF (Attribute-Relation File Format) and Excel files format CSV (Comma-Separated Values). In the case study, all algorithms available in the Weka software tool were applied in the model training phase, but the paper presents two algorithms that had the best results in model testing. These algorithms are Decision Table and Random Forest, and they are described below.

The Decision Table is a machine learning algorithm that is arranged as a set of If-Then rules. This algorithm is used to analyze a dataset by using a decision table that contains the same number of attributes as the original dataset. He evaluates subsets of attributes using the “first best” search based on the method of the nearest neighbor and applying cross-validation (Kohavi, 1995; Kalmegh, 2018). The Decision Table algorithm is in the Rules category in the Weka software tool.

The Random Forest is a machine learning algorithm used to solve regression and classification problems. It combines multiple different algorithms to create a prediction. The Random Forest consists of many decision making trees based on whose predictions determine the outcome i.e. the final outcome is determined based on a majority vote. The algorithm gives a prediction based on averages from different trees. The structure of the decision making tree can be described as a tree made up of nodes connected by branches. The Random Forest reduces overfitting of datasets and increases accuracy (Breiman, 2001). This algorithm is in the Trees category in the Weka software tool.

3. CASE STUDY

Employees in the procurement sector monitor the demand, sales and changes that are happening on the market then analyze them to make a decision on ordering an adequate range and quantity of goods. This decision represents a particular challenge for employees because it is necessary to order the optimal quantity of goods that will not lead to situations where the company runs out of stock or has an excessive level of stock. Both situations create certain costs. Lack of stock creates the cost of missed opportunities, that is, the inability to respond to customer requests. On the other hand, an excessive level of inventory creates higher costs of storing goods. The goal is to avoid both situations and not create unnecessary costs, and this is achieved by ordering an adequate quantity of goods. Modern technologies can facilitate and accelerate the process of ordering goods, in relation to the traditional way of ordering. The application of machine learning models has great potential in the supply chain, among other things for prediction demand and optimizing inventory.

In this case study, the daily demand of five products was predicted based on data obtained from Milšped. Milšped is a logistics provider that offers warehousing and transportation services, so it cooperates with clients and customers. Clients are companies that store their goods in the logistics provider's warehouse, and customers are retail stores that distribute goods. According to customer requirements, the dynamics of the output of goods from the warehouse can be monitored, on the basis of which the provider plans future demand. The obtained data is encrypted for security and confidentiality. As independent attributes affecting commodity demand, they are selected: product, day, month, day of the week (Monday to Friday), while the target variable is the quantity of goods demanded.

Data cover the period from January 2018 to September 2019 were used to train the model, and data cover the period from October 2019 to September 2020 were used to test the model. The initial available dataset contains 352.740 instances with information on the ordering date, purchase order number, product, customer and quantity of ordered goods. As the aim of the case study is to predict the demand for five products, certain data were neglected and only those related to the date and quantity of demand for five products were observed. In the data preparation phase, the data was "cleaned" by generating and executing SQL (Structured Query Language) queries on the entire available dataset. The training dataset consists of 1911 instances and the test dataset of 1262 instances.

4. RESULTS AND ANALYSIS OF RESULTS

In the data mining software tool Weka conducted the process of machine learning and prediction of daily demand for five products. Table 1 shows the performance of the two predictive algorithms measured on the training dataset, obtained using 10-fold cross-validation. Cross-validation is a statistical method for obtaining a reliable model performance assessment using only training data (Witten and Frank, 2005). Most of the algorithms tested gave excellent results, but two algorithms with the best results were presented: Decision Table and Random Forest. The excellent result of the model implies that the correlation coefficient is greater than 0.9, indicating that further analysis of the data may continued.

Table 1. Performance of Prediction Models obtained using Training Dataset

Algorithm	Correlation coefficient	Mean absolute error	Square root of mean square error	Relative absolute error (%)	Root relative square error (%)
Decision Table	0.965	219.184	367.071	19.368	26.205
Random Forest	0.961	232.368	383.471	20.534	27.376

Table 2 shows the performance for the best algorithms measured on the test dataset. A comparative analysis of the obtained performance of the algorithms measured on the dataset for testing and training shows that the results of the training algorithms are slightly better. Precisely such results indicate that there is no problem of overfitting and that algorithms can be used for prediction (Janković and Mladenović, 2020).

Table 2. Performance of Prediction Models obtained using Test Dataset

Algorithm	Correlation coefficient	Mean absolute error	Square root of mean square error	Relative absolute error (%)	Root relative square error (%)
Decision Table	0.946	330.688	487.550	28.970	36.865
Random Forest	0.941	321.890	512.617	28.199	38.760

Figure 1 presents five diagrams, which show the relationship between actual and projected demand, obtained on the test dataset, separately for each product in the third quarter of 2020 year. The blue line represents the actual quantity of demand on the test dataset, the black line represents the projected quantity obtained by the Random Forest algorithm, while the dashed orange line represents the projected quantity obtained by the Decision Table algorithm. From the five diagrams shown, it can be observed that the prediction of daily demand for products, obtained by the Random Forest algorithm, better follows the actual values of quantities than the projected values obtained by the Decision Table algorithm. Algorithms gave the best prediction for products 2 and 5, then for product 4, while products 1 and 3 observed a greater deviation between the values of actual and projected quantities. The reason for the greater deviation between the values of actual and projected quantities for product 1 may be the uneven daily demand of quantities that are not common, i.e. there is no specific trend. Such deviations in the dataset have a bad effect on prediction. For product 3, the reason for deviations is lack of data by date on the training dataset. One of the advantages of the Random Forest algorithm is to function well on a large dataset and on a set with a large number of missing data, which is an explanation for why this algorithm gave a better prediction for product 3 compared to the Decision Table algorithm. The forecast of daily demand for goods is shown for all products with the intention of showing how the forecast result is affected by the lack of certain values in the datasets and the becoming of deviation values. The average error in demand for goods obtained by the Random Forest algorithm per product expressed in units piece, from July to September is as follows: product 1 around 11 (in minus), product 2 around 47, product 3 around 116, product 4 around 290 and product 5 around 327. Also, the average error in demand for goods obtained by the Decision Table algorithm is as follows: product 1 around 13 (in minus), product 2 around 60, product 3 around 458, product 4 around 514 and product 5 around 569. The correlation coefficient is higher with the Decision Table algorithm, but the mean absolute error, i.e. the average prediction error is smaller with the Random Forest algorithm, as shown in Table 2 and observed in the diagrams.

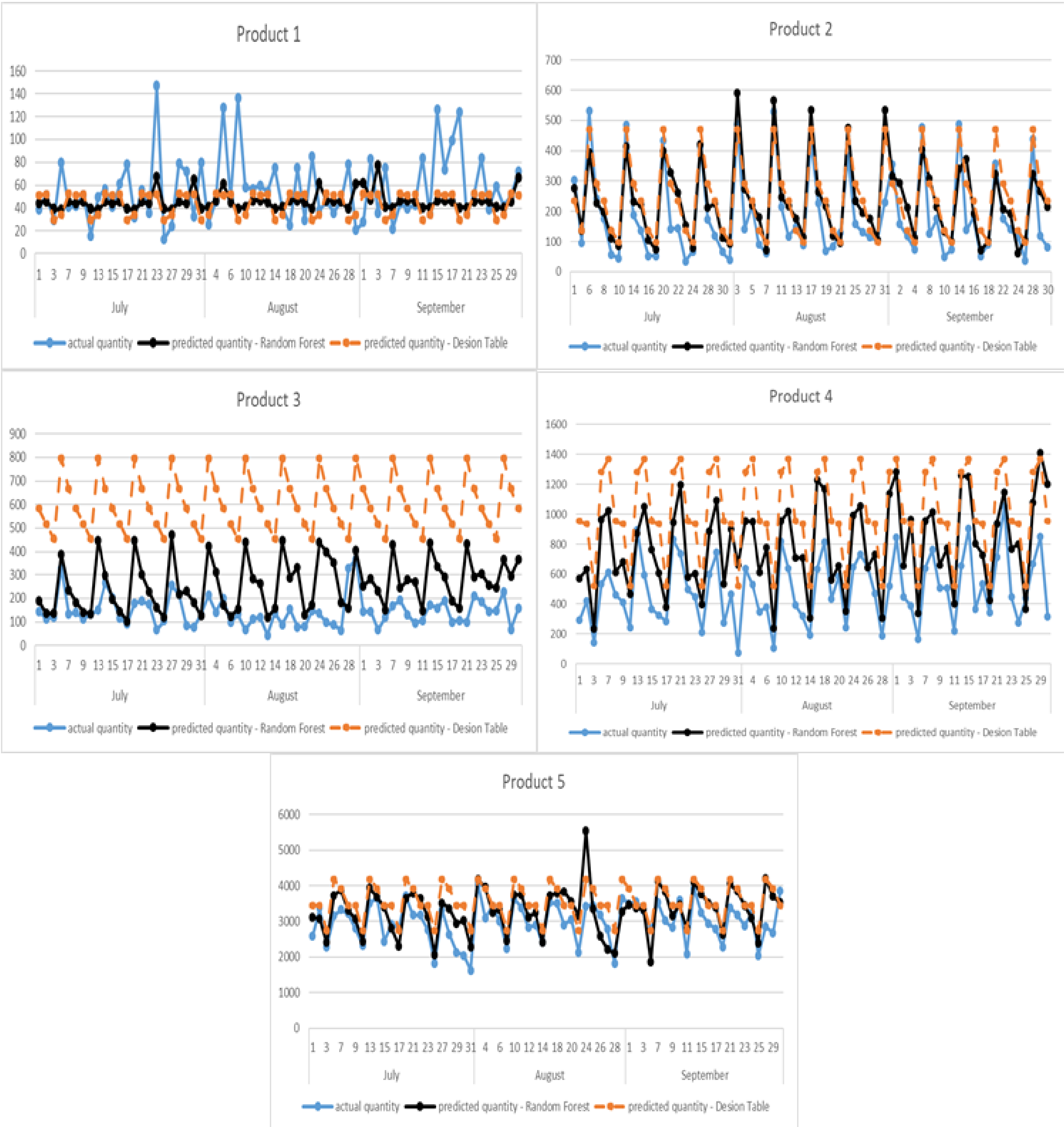

Figure 1. Actual and projected quantity of demand for five products in the third quarter of 2020

Figure 2 shows diagrams for five products showing the ratio of actual and projected demand for goods to the days of the week in June 2020. The perceived trend for products 2, 3, 4 and 5 is higher demand for goods at the beginning of the workweek, followed by a drop in demand. The day of the week when the highest demand for product 2 is Monday, and in the most common cases it is for products 3 and 4, while for product 5 the highest demand is mostly on Tuesdays. Product 1 has not seen a specific recurrence trend and products of this type should always be in inventory because their demand is unpredictable. The results show that by applying machine learning algorithms, good predictions of the target variable can be obtained if the dataset contains quality data for as long as possible. Also, results cannot be predicted until the machine learning process is carried out on a specific dataset. The results show that the predictive models developed in this research cannot be used to predict the demand of all five types of products, but they can be used to predict the demand of product types 2 and 5.

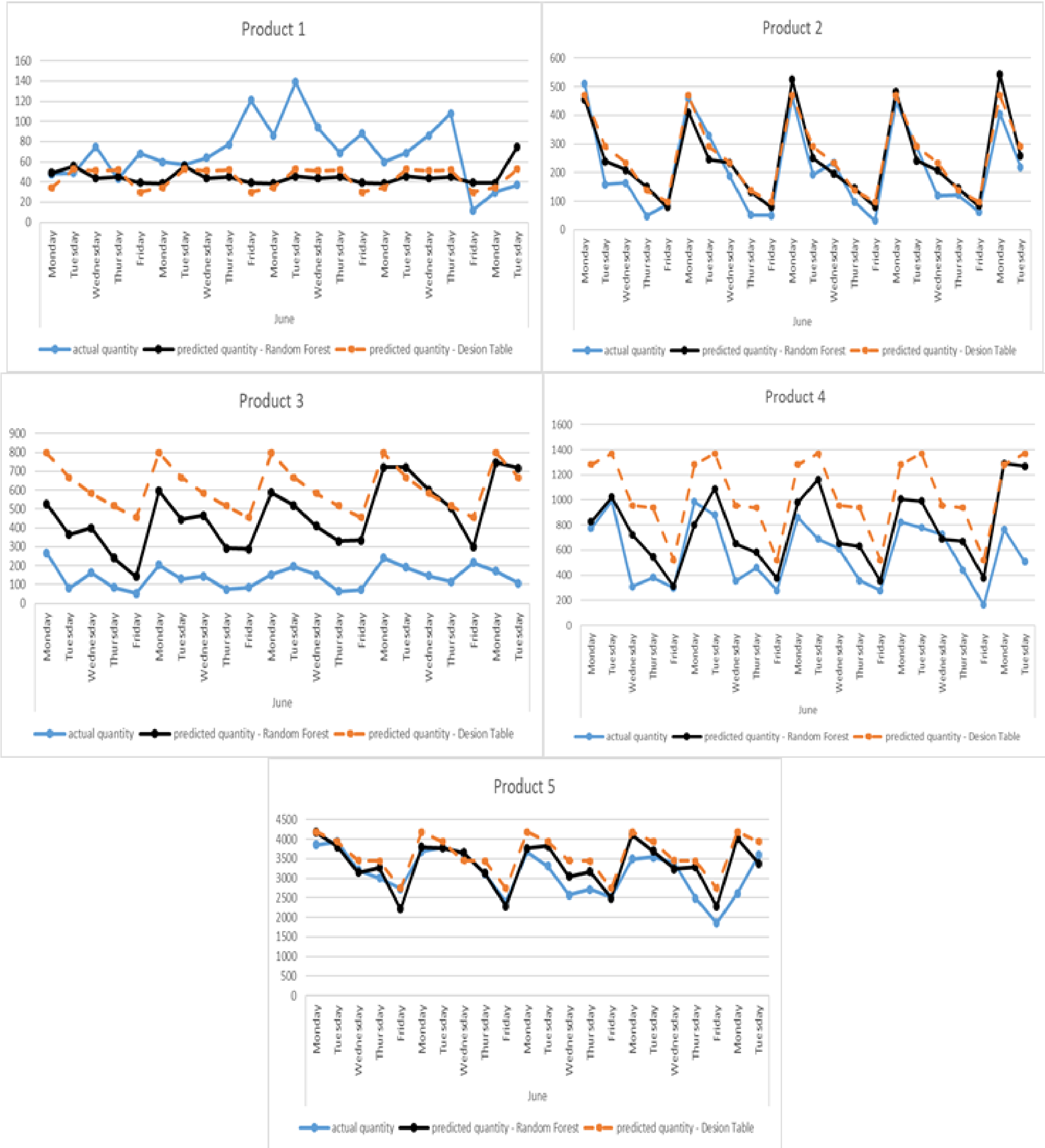

Figure 2. Actual and projected quantity of demand for five products in June 2020

5. CONCLUSION

In this conducted case study for predicting daily demand of five products, models based on the Decision Table and Random Forest algorithms had the best performance. These algorithms showed better performance than other algorithms available in the Weka software tool. Performance of models based on these two algorithms are approximate. The correlation coefficient with the Decision Table algorithm is higher than with the Random Forest algorithm. However, the mean absolute error is smaller with the Random Forest algorithm. On the diagrams shown, it was observed that the prediction by the Random Forest algorithm follows the actual values better than the prediction obtained by the other algorithm. The advantage of the Random Forest algorithm is that it functions well over a large dataset and over a set with a significant number of missing data, as confirmed by this study. The quantity and quality of datasets are of great importance in the application of machine learning models (Zhou et al., 2020). The results of the research indicate a data-driven characteristic of machine learning. The data-driven feature refers to the fact that one machine learning model can give excellent results on one dataset, but at the same time it can be unusable on another dataset, which describes the same phenomenon. The reasons that lead to this problem can be lack of data and diversity of data.

The results of this research prove that machine learning and the application of Weka software tools can be of significant benefit to logistics companies to predict demand for goods. Using data mining tools and machine learning algorithms for certain predictions could help companies better plan, organize, reduce costs, and increase efficiency.

In future research, more attributes related to the demand of goods can be observed to detect certain regularities and patterns in data using machine learning. Then, it would be interesting to predict the demand for goods using time series algorithms from the Forecast tab of the Weka software tool.

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FACTORS THAT INFLUENCE A CHOICE OF AIRPORT BY FREIGHT FORWARDER: SERBIAN, CROATIAN AND SLOVENIAN MARKET

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Abstract: *Choice of airport is a crucial issue from freight forwarder point of view. In order to find optimal solution related to transport of shipment, it is necessary to identify factors that influence an airport choice. It is important to emphasize that airport can attract cargo airlines and freight forwarders if airport is supported by infrastructure such as direct highway access, a fully operational cargo terminal, as well as a positive reputation for cargo established over time. Thus, freight forwarder takes into account all airports within an acceptable radius, considering supply of airlines. The supply includes total costs, structure of price and quality of connections affecting on transport time of shipment. This paper will analyze factors that influence a choice of airport and will illustrate by example of Serbian, Croatian and Slovenian market. The choice of departure airport and appropriate airline is based on real data of above-mentioned factors.*

Keywords: *freight forwarder, airport choice, airline supply*

1. INTRODUCTION

Transport of goods by air, as a mode, fills the need for time-sensitive deliveries over larger distances, especially where the alternative modes, such as road, rail or maritime transport on international or transcontinental routes, are considerably slower. The movement of air cargo from origin to destination using several modes of transport represents intermodal or multimodal transport chain with the air segment as a central leg. Efficiency and sustainability of multimodal transport and logistics can be achieved by using multimodal transport that combines optimally the various modes of transport, exploiting each one's advantages and minimizing the disadvantages (European Commission, 2022).

Air cargo transport is very complex business. It involves different players, very sophisticated processes, a combination of weight and volume, varied priority services, integration and consolidation strategies, and offers many different (possible) routes. Main

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stakeholders involved in air cargo transport are the so-called combination carriers, all-cargo carriers (scheduled or *ad hoc* charter), integrators, contract freighter operators, freight forwarders and consolidators (Doganis, 2002).

Freight forwarders are the link between the airline and the final customer who is the consignor/consignee. They provide services which include consolidation of deliveries from multiple shippers, choice of airport, space reservation on flights of cargo operators or passenger-cargo combination carriers, transport shipment arrangements, to/from freight forwarder' warehouse, to (from) departure (arrival) airport and to final destination as point of delivering shipment.

Freight forwarders are often located landside of an airport or they have warehouses that are located airside or on the border between landside and airside. Generally, from the origin, which is the supplier, to the destination, which is the customer, the process of air cargo transport covers several segments (Fig. 1): 1) transport from pick-up cargo point (supplier) to warehouse (consolidation of shipments), 2) transport from warehouse to the airport A, 3) flight (or several flights) from airport A to airport B, and 4) transport from airport B to the warehouse and further to the final point.

Figure 1. The air cargo chain

Freight forwarder (same as in first part of chain or another) arranges pick-up of shipment from arrival airport (airport B) and organizes transport to its warehouse or another location, and finally delivers it directly to customer (consignee). Accordingly, freight forwarder may offer a service related to the pick-up cargo from supplier, preparation, storage, carriage and final delivery of goods, including all necessary documentation, custom processing and insurance.

The forwarder acts between the shipper and the airport and airlines. The freight forwarder or truck operator provides the ground transport services before and after air transport. The airport through handling agent and airline receives, stores, transfers, tracks, loads and unloads cargo, and assigns and manages capacity.

From the perspective of truck operators and airlines (cargo or combination carrier), freight forwarders are customers and represent demand side of the business while from the shippers' point of view, forwarders are part of supply side, offering transport services in competition with other operators (freight forwarders and integrators), (Morrell and Klein, 2019).

In this paper the focus is on the freight forwarding activity where the main transport mode is air transport. The objective of the paper is to research how freight forwarders choose airport and create supply chain at the air cargo market from shipper to customer, and how to propose different options (offers) to consignor. With the aim to understand the factors influencing the freight forwarder's choice of airport, the case study of an actual location decision by a freight forwarder is adopted. The case study covers three air cargo markets, in Serbia, Croatia and Slovenia.

2. LITERATURE REVIEW

Generally, airports closer to shippers and with lower total costs and shorter delivery times are strong candidates for freight forwarders' choice. Therefore, the most important factors when choosing an airport are geographical location, costs, and delivery times (Park, 2003).

Regarding the most important attributes for selecting cargo carriers in Taiwan, it is revealed that they are reliable and on-time services, possibility for express shipments and a good reputation of the carrier. On the other hand, the highest-rated attributes related to route choice, in the case of forwarders in Taiwan, are: less intermediate stops, efficient handling, and customs clearance service at the destination airport (Chu, 2014).

Competitive factors among airports which offer air cargo service also include infrastructure, customs, intermodal transport, and international aviation policy (Zhang, 2003). Additionally, Gardiner et al. (2005) emphasized that the factors considered by air freight companies when choosing airports include opening hours, total costs, reputation in cargo transport, demands for local O/D cargo, influence of freight forwarders, transport from airports, customs clearance times, and financial incentives offered. As Chao and Yu (2013) stated the opening hours of an airport have a significant impact on airline flight scheduling and timely delivery of transshipment cargo. Shorter cargo clearance times may also reduce cargo transport times and stock costs.

Another significant finding mentioned above by Gardiner et al. (2005) was that freighter operators placed so much importance on the reputation and experience of the airport for handling freighter flights. Results of research conducted by Li (2017) show that "if the freight-forwarding companies know the terminals and transit cities on the routes between origins and destinations, they will not risk trying new routes", even though those routes may result in lower costs and shorter transport time.

3. AIRPORT CHOICE BY FREIGHT FORWARDER

Freight forwarders usually make decisions about airport in the following way. First, based on geographical location, they consider airports that can be reached by truck within acceptable time*. Additionally, they take into account airport capabilities for processing and handle cargo. The availability of modern well-designed and cost-effective cargo facilities is a key advantage in airport attractiveness for freight forwarder. An airport operator is responsible for the provision and security of the airport infrastructure (ICAO-WCO, 2016). Ground handlers are responsible for dealing with operational aspects, based on the instructions of freight forwarders and airlines. Ground handlers' activities encopasses handling, preparing, and tagging cargo and mail, loading/unloading, transit, and storage of cargo and mail.

Second, they compare the total cost and transport time for each airport and appropriate routes from consignor to consignee and analyze trade-off between cost and quality of service (needed time to transport good). Airports often might produce the most delays in supply chain (Morrell and Klein, 2019). Thus, it is important to have data for each airport related to timetable, delays, customs clearance times as well as airports opening hours.

After choosing the airport and the route, negotiations with the airline will begin. One of the issue is how much capacity to book, or how to manage contracted space. Namely, freight forwarder can have contracted space for specific flight for specific day in one week. For other flights and other days, it is necessary to book space. Decision about flight is based on required time to deliver shipment as well as on special requirements related to goods. For example, perishable or dangerous goods must be handled with particular care and under strict procedure.

Further, air carriers can charge by volumetric mass, which is dimensional weight, or by actual weight. Cargo rates are negotiated between airlines and freight forwarders and usually quoted per kg or per ULD. The level of cargo rate is depending on specific product or service as well as on freight forwarder importance and its contribution to airline demand. Generally, rates are not published. The actual rate paid a freight forwarder to an airline may differ from the tariff, and are bilaterally agreed and remain confidential.

Additionally, there is a surcharge as an extra fee, charge, or tax that is added on to the cost of a good or service. Surcharges could include airport handling fee, airport screening fee, airport transfer fee, dangerous goods fee, fuel surcharges, handling fee, letter of credit fee, security surcharge and terminal handling fee (IATA, 2021).

One of the main questions is, what are the deciding factors influencing the freight forwarder choice of airport. In the next section, airport and airlines' supply will be analyzed in order to illustrate input (factors) affecting airport choice for shipment.

4. CASE STUDY: FREIGHT FORWARDER's CHOICE OF AIRPORT

In this section the case study is discussed, focusing on the characteristics of the supply in terms of transport cost and airline timetable. The primary data sources for this case are derived from the real pricelists of the considered airports and airlines. In order to illustrate the choice of airport of freight forwarder, the examples of Serbian, Croatian and Slovenian markets are considered. The example covers following: 1) service "door to airport" will be offered by freight forwarder, 2) the origin point is Belgrade (Serbia), 3) the final destination is Dubai, and 4) three potential departure airports (Belgrade – BEG,

* For example, for the given market, one freight forwarder considers only airports that can be reached by truck within 12 hours.

Zagreb – ZAG, Ljubljana – LJU) and one arrival airport (Dubai International Airport – DXB) are taken into analysis.

The selection of the most appropriate route is based on two criteria: total transport costs and the quality of connection (with respect to airline schedules). In the case study, the airports are ranked first based on total transport costs which include cost of transport to the airport by truck, cost of ground handling and cost of transport by air. Then, for each of the considered airport the quality of the connection is determined based on available airline schedules and the most appropriate route is chosen.

Cost of transport by truck (from consignor to airport), cost of ground handling and airline air cargo rate, as factors that affect the airport choice of freight forwarder, will be analyzed, for different masses of goods (45kg, 100kg, 500 kg, 1000kg, 3000kg). Tables 1-3 display information regarding these costs. Table 1 contains the road transport cost for different masses of goods, from origin to the selected airports. In this example, we consider the transport of general cargo which does not require a special type of handling equipment or service. The truck operator, generally takes into account the cargo mass, dimensions and the number of pallet spaces required. Based on those data, it was determined that goods up to 100 kg can be packed in a vehicle with a capacity of two pallet places. In that case, it would cost 30 euros to be transported to Belgrade Airport, 250 euros to Zagreb Airport, and 280 euros to Ljubljana Airport. For goods over 100 kg and less than 1000 kg it can be transported by a vehicle with four pallet places (van), and goods between 1000 kg and 3000 kg can be transported by a vehicle with 10 pallet places (avia truck). In order for these costs to be comparable, it is necessary to convert them into unit costs per kilogram and this is, also, given in Table 1. It is evident that costs decrease with increasing mass, but it is also observed that the difference in unit costs decreases with increasing mass.

Table 1. Transport cost and unit cost from origin to airport, by truck

Departure airport	Mass of goods				
	45 kg	100 kg	500 kg	1,000 kg	3,000 kg
	Transport cost from origin to airport, by truck, in EUR				
BEG	30	30	70	70	120
ZAG	250	250	350	350	420
LJU	280	280	400	400	510
	Transport unit cost from origin to airport, by truck, in EUR/kg				
BEG	0.66	0.3	0.14	0.07	0.04
ZAG	5.55	2.5	0.7	0.35	0.14
LJU	6.2	2.8	0.8	0.4	0.17

Ground handling cost represents the cost of unloading the goods from the truck, the cost of placing the goods in the customs warehouse at a certain position and the cost of X-ray control of the goods (Table 2). This cost is usually charged by airports as a unit cost per kilogram of actual mass and it can be observed that Belgrade Airport is the cheapest among these airports.

Table 2. Ground handling cost at the airport, in EUR/kg

Departure airport	Mass of goods				
	45 kg	100 kg	500 kg	1,000 kg	3,000 kg
BEG	0.06	0.06	0.06	0.1	0.1
ZAG	0.15	0.15	0.15	0.15	0.15
LJU	0.1	0.1	0.1	0.1	0.1

Table 3 shows the unit cost of air transport service from the departure airport to the destination airport. The airline rates in Table 3 refers to the summer flight schedule in 2018. Although, the airline rates decrease with the mass of goods transported, the airline from Belgrade airport charges the highest prices in all cases, while from Zagreb airport is the cheapest. Generally, airlines determine rate based on simple calculation. To calculate the volumetric mass, first the volume should be determined: length multiply by width multiply by height (all values in centimeters). Then this number should be divided by 6,000.00 for air freight (for other mode of transport this value is different), (IATA, 2021). The final shipping costs are calculated based on the highest value of the actual and volumetric mass: this is the "chargeable mass".

Regarding this case study, there are two assumptions:

- aircraft capacity issue is not considered (i.e. available capacity is sufficient),
- the chargeable mass is actual mass (kg).

Table 3. Airline rates – transport cost by plane, in EUR/kg

Departure airport	Mass of goods				
	45 kg	100 kg	500 kg	1,000 kg	3,000 kg
BEG	2.37	2.21	2.05	1.9	1.77
ZAG	2.22	2.12	1.75	1.35	1.25
LJU	2.35	2.22	1.92	1.88	1.05

To determine which route is the most cost-effective, a freight forwarder needs to sum up the following: a) the cost of transport to the departure airport; b) the cost of ground handling, and c) the cost of air transport from the departure airport to the destination airport. Table 4 summarizes the costs of door-to-airport services. Based on this total cost Belgrade airport is the first choice for goods up to 500 kg, Zagreb airport is the first choice for goods of 1000 kg and Ljubljana airport is the most suitable for goods of 3000 kg. Note that total transport costs vary from airport to airport depending on the mass of goods. Moreover, the difference among unit costs of transport from origin to the departure airports (Table 1) decrease with increasing mass.

Table 4. Total transport cost from door to arrival airport, in EUR/kg

Departure airport	Mass of goods				
	45 kg	100 kg	500 kg	1,000 kg	3,000 kg
BEG	3.09	2.57	2.25	2.07	1.91
ZAG	7.92	4.77	2.6	1.85	1.54
LJU	8.65	5.12	2.82	2.38	1.32

In case that the clients are not only interested in the total transport costs, but also take into account the transit time and the quality of the connection at the given airports, then it is necessary to analyze the flight schedule of the airlines. The available flights and departure timings for the selected departure airports and destination airport are given in Table 5. The data used is collected from Flight radar between July 30 and August 8, 2020.

Table 5. Airline supply from Belgrade, Zagreb and Ljubljana to Dubai

FLIGHT WITH ONE STOP	AIRLINE OFFERS: TIMETABLE, AIRCRAFT TYPE			
	FIRST LEG		SECOND LEG	
BEG-DBX	**BEG-IST** TK6575 A310F	31.07.2020. DEP. 17:30 ARR. 19:10	**IST-DBX** TK760 B777W	01.08.2020. DEP. 18:10 ARR. 23:43
ZAG-DBX	**ZAG-CDG** AF6767 B767F	31.07.2020. DEP. 21:40 ARR. 23:40	**CDG-DBX** AF662 A350	01.08.2020. DEP. 13:45 ARR. 22:35
LJU-DBX	**LJU-MOW** SU2611 A320	01.08.2020. DEP. ---- ARR. ----	**MOW-DBX** SU521 B737	02.08.2020. DEP. ---- ARR. ----

The *NetScanCargo* model is than used to quantify the performance of air transport networks, i.e., to measure the quality of a network's indirect connections (Boonekamp and Burghouwt, 2017). Main parameters are given in Table 6.

In order to achieve $T_{max} \approx 48$h, time sensitive parameter (α) and correction parameter for short flights (τ) are chosen to be $\alpha = 15$ and $\tau=0.5$. It should be noted that a higher value of α indicates a lower time-sensitivity. Regarding parameter τ, it is included to allow for a little more time flexibility for short flights. These parameters are determined based on the freight forwarders' historic data.

Connectivity is a measure of accessibility and centrality of airports, regions and countries, while accessibility denotes the extent to which an airport provides connections to other world regions. It should be noted that this accessibility relates to airside accessibility and it should not be confused with landside accessibility (i.e., accessibility by road, rail or maritime transport), Burghouwt and Redondi (2013).

Table 6. Net Scan Cargo model

Parameters	Description	BEG-DXB	ZAG-DXB
Frequency (f)	Weekly number of flights	1	1
$T_{nonstop}$	Theoretical non-stop flying time	5.33	5.66
T_{max}	Maximum acceptable transport time	47.64	49.29
T_{fly}	In-flight time	6.79	10.33
$T_{transfer}$	Transfer time	23	9.91
$T_{perceived}$	Perceived travel time is a linear function of the total in-flight time, transhipment time and a penalty for the inconvenience of a transhipment.	29.79	20.24
$P_{perceived} - T_{nonstop}$	Difference between indirect and direct non-stop flight time	24.46	14.58
$T_{max} - T_{nonstop}$	Maximum allowed difference between indirect and direct non-stop flight time	42.31	43.63
q	Quality of the connection	0.42	0.67
CNU= q*f	Connectivity network unit	0.42	0.67

The amount of CNU on a certain route is determined by the system of equations given by Boonekamp and Burghouwt (2017). Considering data related to airlines' offer from selected airport, it is observed that flights from Ljubljana are performed by inappropriate aircraft type; therefore, the value of CNU for Ljubljana – Dubai is equal to zero, and the airport in Ljubljana is excluded from further consideration. The values of CNU for Belgrade – Dubai is equal to 0.42, while for Zagreb – Dubai CNU is equal to 0.67 (Table 6).

Adding information related to CNU to previously determined costs (Table 4), Zagreb appears as the most suitable airport for larger shipments (1000 kg or more), while Belgrade still is the best option for shipments up to 500 kg.

However, to make final choice of the airport, freight forwarder needs to take into account maximum transit time required by consignor. Depending on this time, and bearing in mind that departure times of flights are fixed, the freight forwarder would decide whether the requirements can be meet or not, and under what conditions. Moreover, if shipments need to be sent periodically, then airline's flight schedule can be limiting factor.

5. CONCLUSION

This paper presents an analysis of airport choice by freight forwarder located in Serbia. In most circumstances, the attractiveness of an airport depends on the characteristics of the supply in terms of transport cost and airline flight schedule. For the sake of this paper, an airline flight schedule is evaluated in terms of transit time and the quality of the connection at the given airports.

Belgrade airport is generally cost-effective in term of transport costs, due to its proximity. However, the shipping rates offered by airlines tend to be high in comparison to the Zagreb and Ljubljana, which put them in first choice for higher masses (over 1000 kg).

Moreover, for high-volume shipments, truck operators offer discounted shipping rates and in those cases Zagreb and Ljubljana can be cost-effective, too.

In terms of quality of the connections, there is a large difference between considered airports (Belgrade, Zagreb and Ljubljana) in their role as cargo airports. Ljubljana airport offers very limited number of cargo services, while the situation at Belgrade and Zagreb airports is much better which makes two of them very competitive.

There are a number of areas for further research. A thorough survey of the freight forwarder airport choice should be conducted in order to develop a choice model based on real data. Moreover, it would be interesting to assess the preference of cargo routings for freight forwarders and which route characteristics determine their choice. Also, the role of road transport in air cargo networks in this part of the Europe should be studied, too.

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PART VI WAREHOUSING AND MATERIALS HANDLING

FRAMEWORK FOR IMPROVING WAREHOUSE SAFETY

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Abstract: *Warehouses are a crucial component of every supply chain. They are undergoing a transition of goods flows, necessitating the implementation of intensive warehousing, transportation, and transshipment operations with products. The necessity for safety is becoming more obvious in many areas nowadays. Logistics, and especially warehousing, is one of the domains where these requirements are most prominent. The safety of warehouse work operations is divided into three categories: occupational safety, workplace safety, work safety, and fire safety. The major objective of this research was to offer a methodical approach to warehouse management and safety improvement. This method, which is based on systems analysis principles, has nine basic steps: Identification of the need for safety management, analysis of the current situation, identification of risk generators and hazards posed by generators, risk analysis, preventive and corrective measures, investments and investment effects, training staff, and periodic and continuous checks of system.*

Keywords: *Safety, warehouse, methodological approach, risk, systematic analysis*

1. INTRODUCTION

Warehouses, as a component of logistics, play a vital role in the execution of supply chain process. An intentional transformation of goods flows occurs as a result of their participation in them, demanding the implementation of extensive storage, transportation, and handling operations with products (unloading, transshipment, loading, internal transport, storage, etc.). Warehouses as a whole appear to be areas where different types of accidents can occur, resulting in employee injuries or death, as well as material damage (Richards, 2018; Hofstra et al., 2018). The safety of storage operations is a complex and ambiguous topic that spans three main areas: work safety, workplace safety, and fire safety (Vukićević, 1995).

In recent years, the issue of warehouse safety has become more frequent in practice and more important. Warehouse managers are increasingly interested in providing a safe workplace environment in which the frequency of accidents resulting in increased material damage or human casualties is maintained to a minimum (Richards, 2018, De Koster 2010, Mariani, 2017). Although ideal conditions are not possible due to the nature

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and characteristics of storage processes, accidents are likely to happen. However, it should be influenced so that accidents are as infrequent as possible and their effects are as minor as possible. In light of the foregoing, there is a requirement / need for increasing warehouse safety to become a continual operation. Legislation, rules, standards, good practice guides, scientific and professional papers, publications, and other resources should all be used to assist in these efforts. This document was written in the hopes of helping in that direction. The purpose of this paper is to propose a methodological framework/approach that enables the problem of warehouse safety to be set/observed in a thorough and systematic method. This varies from the majority of publications in the literature, which tackle the topic of warehouse safety in fragments, focusing only on discrete areas / aspects of the problem. On the one hand, the proposed methodological procedure in this paper is a beneficial tool for risk reduction, more efficient regulatory compliance, and a faster certification process, while on the other hand, it is a great beginning point for future research topics.

There are several parts in the paper. The second part, after the introduction, explains the issues and literature reviews. The third part outlines a methodology for improving warehouse safety. The algorithm's steps are processed within that. The objectives for safety management and an assessment of the current situation were identified first. Potential risk generators and the roles they can play were then identified. A risk analysis was also conducted, as well as proposed corrective and preventative measures to eliminate and reduce the risk. Finally, risk management investments and consequences are explored. This is a cyclical and continuous process.

2. FORMULATION OF THE PROBLEM AND LITERATURE REVIEW

2.1 Formulation of the problem

According to international sources, various warehouse accidents occur often, with levels of severity (even fatalities). At the same time, accidents in this sphere may have a significant impact on the quality of warehousing processes and thus the supply chain as a whole, in addition to the stated disadvantages related to injuries / deaths of people, damage to goods, delays in the implementation of the process (flow of goods), etc.

With the above in mind, it's worth evaluating the potential areas of risk that could be generated in warehouses with a high workload (such as trade warehouses, distribution warehouses, and etc). Furthermore, given the potential consequences, it is important for specialists in this area to consider courses of action / methods that can be used to reduce or perhaps eliminate the risks involved. As a result, there is a need for a single, easy-to-use method that can help with warehouse management and safety.

2.2 Literature review

Warehouse safety is a topic that has received much attention in the literature and in practice. The majority of academic publications deal with challenges of partial safety. Some publications focus on: (i) risk assessment only (Andrejic et al, 2020), (ii) methods (Purohit et al, 2018), (iii) only corrective actions or regulations (De Koster et al, 2011; Venkateswaran 2013), and (iv) only solving some specific safety issues (Lam et al, 2015). However, no publication examines and analyzes all of these aspects in depth, resulting in a comprehensive methodological approach for measuring warehouse safety.

Many engineers in the company, in addition to research, are working on this issue. They define a methodology for resolving limitations in the literature and enabling practical answers to specific issues. NZI Risk Solutions is one such company. They are in responsible of risk evaluations in certain warehouses. They offer advise on how to reduce risks in individual warehouses based on their practical experience. The Warehouse risk management guide (2019) is an instruction on how to handle warehouse hazards in their job. They take into account a huge number of warehouse processes and make recommendations for them based on specified standards. Fire and flood protection, protection of the working environment, protection of warehouses from external attacks, and other topics were covered.

3. METODOLOGICAL FRAMEWORK FOR IMPROVING WAREHOUSE SAFETY

Starting with the task's complexity, a logical strategy to assessing warehouse safety and removing possible risks, which is incredibly hard, is imposed. It is made up of many steps (see Figure 1): Identification of the need for safety management, analysis of the current situation, identification of risk generators and hazards posed by generators, risk analysis, preventive and corrective measures, investments and investment effects, training staff, and periodic and continuous checks of system. These steps are instructed chronologically on the diagram, but they can also be iterated.

This algorithm is the result of many years of practice and theoretical and practical research. As a result, the created methodology overcomes all of the detected issues and solves the major gaps. The following section of this paper will go over the complete algorithm with more details.

3.1 Identification of the need for safety management

It is necessary to identify the needs for risk management at the beginning of the risk analysis in the warehouse. Material damage, personnel injury, user displeasure, primary legislation, or the formation of standards are the most frequent cause. The law can refer to the Law on Workplace Safety and Health, while ISO 45001: 2018 is the most well-known standard dealing with workplace health and safety.

3.2 Analysis of the current situation (As-is analysis)

When it comes to safety, a preliminary and unavoidable analysis of the current situation is important because it identifies the need for safety management. Managers must analyze the issues that exist in the warehouse in order to analyze them and give recommendations for their solutions. They must also take into account the safety measures already in place. This assessment should include all important aspects of the warehouse that allow it to function (facilities, equipment, employees, applied technological solutions, applied safety measures and systems, etc.). The analysis' results should assist to identify issue areas, or accident generators.

There are several approaches to analyzing the current situation. Process decomposition and mapping is one of them. Interviews, surveys, checklists, field recordings, and other methods are also used. When it comes to safety, this phase is unavoidable because it identifies the need for safety management.

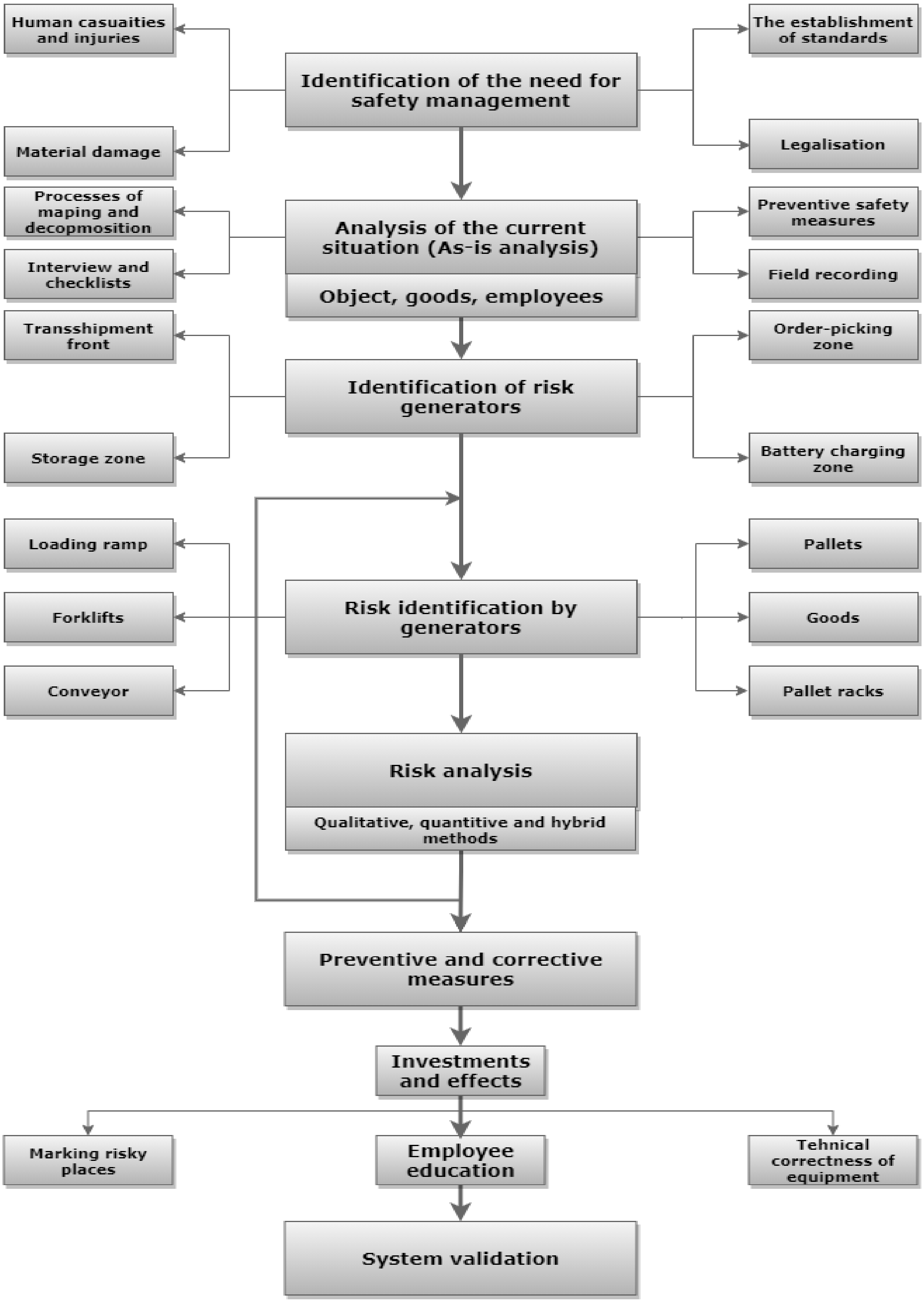

Figure 1 - A methodological approach to determining warehouse safety

3.3 Identification of risk generators

As a result of the above study, possible hazard areas were identified. Depending on the study, these risks may occur in various areas in storage system. The transshipment front, storage and order-picking zone, charging zone for forklift batteries, aisles, and other sensitive areas are frequent. Loading and unloading goods into and out of trucks and racks, storage and order picking, declaration and labeling, sorting, and other activities are managed in these zones. Some parts of the warehouse will be processed in greater detail in the future. Especially those in which there is a higher risk of damage to goods and other warehouse elements, as well as employee injuries[*].

In warehouse are performs four main processes: receiving, handling, storage, and shipment. On the transshipment front, these operations result in reciving and shiping. The transshipment front is the area of the warehouse that communicates with the outside world, allowing items to be received and dispatched to and from the warehouse. Physical, quantitative, and qualitative receiving and dispatch actions are carried out within these procedures. In technological terms, the front of palletized goods transshipment can be seen as a site / point connecting the incoming flow from the environment with the warehouse on the one hand, and the processing / storage zone with the flow from the warehouse to the environment on the other. In these situations, intensive transit and handling processes, especially in commercial warehouses, are carried out, increasing the risk[†].

In the **storage / order-picking zone**[‡], two main warehousing operations are used. These include goods storage and some types of handling. Storage goods is a static process that involves the suspension of items in order to supply some of the warehouse's basic functions (accumulation, provision of reserves, etc.). Order-picking and sorting can be done in the storage zone when it comes to processing. In addition to racks and goods, the storage zone has various transport and handling equipment (forklifts, carriages, etc.), conveyors, and employees who cooperate with warehousing operations. The specific area is characterized by storage zones with a temperature range in terms of safety (chambers). Work is carried out in these zones at extremely low temperatures, providing an uncomfortable working environment.

3.4 Risk identification by generators

Risk is defined as the possibility of a negative departure from the expected outcome. As a result, risk encompasses all factors that have the potential to positively or negatively effect the achievement of a particular goal. Risk is defined as the potential of a negative or unexpected consequence. A risk is any action or activity that results in a loss of any kind (Ivanov 2020).

The first phase of the risk management process is risk identification, which identifies risks that could affect the execution of planned activities. Internal and external factors are also

[*] https://logistikaitransport.com/wp-content/uploads/2020/02/Bezbednost-u-skladistima-White-Paper-1.pdf

[†] https://www.nzi.co.nz/content/dam/iag/nz/images/commercial/nzi/documents-and-forms/risk-solution-guides/NZI%20Warehousing%20Risk%20Management%20Guide.pdf

[‡] When storage and order-picking zones share the same storage aisles, they frequently exist in warehouses in a hybrid form generated vertically by separating the storage rack. Warehousing and order-picking activities are carried out over these zones, which creates a potential threat in and of itself.

included in the risk identification process. Identifying situations that may have a negative effect on the implementation of specific activities is known as risk identification. A number of tools are used to identify risks: Checklists, interviews, cause and effect diagrams, the Delphi method, and others are within them (Richards, 2018).

According to UK research[*], most common causes of warehouse injuries are: inappropriate forklift use, improper product stacking, lack of safety equipment, frequent repetition of the same movements, and others. In addition to the usual risks, the warehouse contains a number of others. For the purposes of this paper and in accordance with the preceding point, the following components can be identified as potential areas of accident in the warehouse: loading and unloading ramp, forklifts, conveyors, pallets, goods, racks, etc. Because of the complexity of the problem, this paper will concentrate on the components of the storage system that are most involved in the implementation of storage processes and are the most common sources of accidents: transshipment fronts, pallet racks, and forklifts (Richards, 2018).

Equipment and employees generate different risks on **the loading and unloading ramps (on the transshipment front)**. The ramp can be moved independent of the vehicle. This can result in the items on the truck falling and breaking, or the entire vehicle overturning. Material damage results from the items falling and breaking, with the amount depending on the quality and quantity of the commodities, whilst the forklift flipping might result in severe bodily injury to the forklift driver in addition to material damage. Furthermore, the forklift's uncorrected speed along the ramp can have the same effect.

Forklifts are potential of being involved in a lot of accidents: falling goods from the forklift ; collision of two forklifts; forklift impact on personnel; overturning; and forklift impact on static warehouse equipment just are a few examples. Forklift accidents can result in major material damage as well as human casualties (De Coster et al, 2011).

Pallet **racks** must be considered in additional to the possible causes of accidents. There are many different types of these racks, but selective pallet racks are the most typical. Because the pallet can fall out of the rack, accidents can happen. A broken pallet, a forklift blow to the rack, or poor pallet holding / disposal are some of the causes. Đurđević and Miljuš 's study on this topic provide more information (2013). Risks to generators can be represented by specific matrices. It is necessary to confront generators and risks in the matrix and determine the connection between them.

3.5 Risk analysis - strategies for calculating risk

To efficiently control risks, one must also evaluate the level of risk and whether or not it is necessary to manage this risk. There are many methods for performing such calculations today. These methods can be classified as qualitative, quantitative, or hybrid. Risk is calculated using quantitative methods as a function of the probability of occurrence and the degree of the consequences. Both elements must be expressed numerically in order to provide a thorough quantification of the risk. Qualitative approaches are dependent on the assessment maker's experience. These methods do not require knowledge of earlier activities, but they provide linguistic value (low risk, high risk, etc.). Because the probability of occurrence and the size of the risk's repercussions are difficult to determine in some situations, hybrid methods are frequently used. The

[*] Which she carried out OSHA (Occupational Safety and Health Administration)

matrix, tabular, and graphical methods of risk assessment are three methodologies of determining the risk of these methods. Table 1 lists some of these methods. Accident statistics can be utilized for risk analysis in addition to the methods mentioned above.

Table 1 - Most frequent risk assessment techniques.

The method's name	Consider the following factors	Form for calculating risk
KINEY method	-disease probability (V) -exposure to risks / hazards' frequency and duration (U) -consequences (P), that is, the severity of any actual risks or disease	R = V x U x P
PILZ method	-disease probability (V) -exposure to risks / hazards' frequency and duration (U) -consequences (P), that is, the severity of any actual risks or disease -number of people who are at risk (B)	R = V x U x P x B
GUARDMASTER method	-disease probability (V) -exposure to risks / hazards' frequency and duration (U) -consequences (P), that is, the severity of any actual risks or disease	R = V + U + P
FINE method	-the probability of disease or injury (P) -number of risky events (E) -possible disease or injury consequences (C)	R = P x E x C
FMEA method	-severity (S) -probability of occurrence (O) - detection (D)	RPN = S x O x D

3.6 Suggestions for risk reduction and elimination

There are numerous methodologies for reducing and eliminating risks in the warehouse, depending on type of risks. Many of these approaches can be implemented with modest financial investments while providing significant rates of return due to the efficacy of their design. The hierarchy of controls includes: (i) elimination (remove the hazard from the workplace), (ii) substitution (replace a high-risk situation with a low-risk situation), (iii) engineering controls (use technology to prevent an exposure), (iv) administrative controls (use programs or policies to prevent an exposure) and (v) PPE (as a final layer of protection). This point builds on the previous one by offering approaches to reducing the identified potential risks. Checklists can be used in the warehouse as a method of internal verification. They may be used to check the amount of safety in each warehouse rapidly and continually. Furthermore, essential areas in the warehouse must be identified and labeled. This can be accomplished by using diagrams and sketches as warnings. Preventive or corrective measures can be suggested to reduce the risk. Preventive steps are being taken to avoid accidents, while corrective actions are performed after an accident (Schwartz, 2021).

To reduce risk throughout the loading and unloading operation, the forklift's speed must first be adapted to the current conditions. It's also important that the loading / unloading ramp can resist the anticipated loads and is securely fastened to the vehicle and warehouse. When it comes to crossings and platforms, forklifts should move in the middle of them rather than on edges. Employees must adhere to defined procedures and follow established norms. One of these regulations is to enter and exit the cargo space of external transport vehicles using ladders and other aids instead of jumping out.

It is essential to influence **forklifts** when it comes to their impact on reducing risks in warehouses. In most cases, their ignorance and incompetence can result in accidents. As a result, forklift drivers must possess the requisite certificates to operate forklifts. It is also vital to adapt movement speeds to the current warehouse conditions, especially on slick surfaces and in narrow passages. Another characteristic of forklifts is their technical correctness. It is necessary to check the technical condition and monitor the wear of wearing elements on a regular basis (e.g., tires). Forklift drivers should follow the procedures for lifting, lowering, and depositing loads, but they should also consider the forklift's characteristics. To reduce the risk of personal injury, they should also use forklift seat belts. Indoor forklifts with no CO_2 emission should be used. If this is not possible, a ventilation system that minimizes the percentage of this gas in the air should be implemented[*].

The majority of rack-related accidents are reported in advance. It is necessary to stack the items in them in the correct manner and, if necessary, fasten them with individual aspects in order to avoid some of the accidents. The aisles between the racks should be kept clear on a regular basis, and large goods should be placed at lower levels (Đurđević i Miljuš, 2013).

3.7 Investments and their effects

When a risk analysis determines that a deeper examination of a particular risk is necessary, preventive and corrective actions to eliminate or reduce the risk are proposed. After that, managers must calculate how much money need for execute the plan, as well as the benefits who will get. It is important for the effects to be greater than the cost in order to be rational about investing in risk elimination.

3.8 Employee education and system validation

It is necessary to conduct frequent employee training in order to improve the warehouse's safety level to an acceptable standard. Workers must be taught in order to reduce warehouse risks, based on the previous step and the definition of important points and safety procedures. Engineers suggest that employees often do not even understand the basic rules and procedures, thus this approach is preventive and primary. Especially, because employees frequently change tasks, it is vital to educate all employees with all potential risks. This phase is repeated at periodic times that are controlled by a variety of circumstances. A checklist can also be used to undertake continuous (regular) system checks.

[*] https://www.nzi.co.nz/content/dam/iag/nz/images/commercial/nzi/documents-and-forms/risk-solution-guides/NZI%20Warehousing%20Risk%20Management%20Guide.pdf

4. CONCLUSION

Safety has become a popular topic across many industries. As a result, the warehouse is assigned a high degree of importance. The fact that an increasing number of warehouses employ experts who deal with this issue support the conclusion. The safety of dangerous goods warehouses is especially significant. It should not, however, be ignored in traditional distribution warehouses. They have less risks and consequences, yet they can still cause significant material damage and human casualties.

There are many procedures and regulations that deal with this topic and define the rules of conduct and the manner in which goods should be managed in limited cases. Storage zones, aisles, transshipment fronts, and recharging zones for electric forklift batteries are all identified as sensitive areas where bad actions can occur when it comes to safety in distribution warehouses. It is important to pay careful attention to risks in these areas and work to eliminate or reduce them.

The methodology / procedure given in this study provides a comprehensive and methodical approach to solving problems of this nature. This procedure for identifying warehouse risks definitely minimizes risks that compromise warehouse safety, which has a direct effect on cost reduction by reducing sick leave and absence of workers, as well as the elimination of material damage to equipment. It also makes it very easy to comply with legal requirements and reduces the penalties imposed by competent inspections. It also includes a complete system implementation for the introduction of standard specifications (OHSAS and ISO 45001).

This paper can serve as a basis for further investigation in a variety of directions. The first step is to apply the proposed method to the test on real life scenarios. Additionally, the paper can be improved by inventing new risk assessment and management methods hybrid model. With certain modifications and adjustments, developed algorithm can be used for improving safety in other logistics systems and subsystems. This represents the third direction of future research. Additionally, it can be used as a decision-making tool.

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DIMENSIONING BLOCK STACKING SYSTEMS

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Abstract: *Palletized unit loads can be stored in several different ways. There are technologies with storage equipment and technologies without storage equipment. The oldest storage technology is block stacking system, which is still in use today. This technology only needs space, not storage equipment. This greatly reduces storage costs, but there are certain limitations in terms of selectivity, accessibility, and etc. This system should be optimized in order to make the best use of storage capacity/space. Dimensioning, which is the subject of this study, is one of the subjects of optimization. The goal is to demonstrate several approaches to dimensioning the block stacking system based on the characteristics of the problem to be solved. Methods for determining the optimal lane depth, and many other dimensions, will be presented in this paper. In addition, relevant papers on this topic will be presented and briefly discussed.*

Keywords: *Warehouse, Block staking systems, Dimension problem*

1. INTRODUCTION

Warehouse is a very important link in the supply chain, with specific tasks. One of the basic tasks / functions of the warehouse is storage, i.e., temporary retention of goods, with the intention to use them soon. This arise an additional question, which storage technology needs to be applied to realize this function. When it comes to the storage of palletized loads units, it is possible to apply technologies with and without the use of storage equipment (racks) (Vukićević, 1995).

A block stacking system is used to store unit load on top of each other on the warehouse floor. Different schemes are utilized in the constructing blocks to offer storage conditions and rational handling. At the end of the lane, the first pallet is placed on the floor, and the second one is placed on top of the first. If there is enough height, the third pallet can be placed on top of these two. If not, it needs to be set in the front of the first. This is how further filling actually in daily practice occurs. One lane usually contains only one SKU (stock keeping unit), and it can only be utilized to store another SKU after it has been completely empty. As a result, many lanes are only partially filled at some point through

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the storage process. *Honeycombing* is the recognized term for this effect. The number of pallets that can be stored in height is determined by the load's weight and stability, the handling equipment's characteristics, and the space's available height. In practice, four levels of agreement are the most usual. Because the pallets are kept in reverse order, the LIFO (*Last-In-First-Out*) storage method is applied (Rushton et al, 2014).

This storage system characterized low costs. Therefore, it is widely utilized in many manufacturing and non-manufacturing industries, as well as distribution centers, as the primary storage system. In the case when there are many pallets of one product in stock and several pallets are sent at the same time, the block stacking system is extremely efficient (Tompkins et al, 2010).

When storing big and difficult pallets, box, or containers, block stacking is also cost-effective and widely accepted. Bottled beverage firms, the food sector, the building materials industry, some distribution warehouses, and sea shipping ports all employ these systems.

Before deciding on block stacking system, it is necessary to evaluate the task, for which the following information is required: about the items, the characteristics of the goods flow (receipt-shipment); and the available space and its characteristics. The storage area is created in accordance with the task and the goals. The capacity, number of aisles and cross aisles, number of lanes, lane depth, stacking height, and other parameters are calculated during the dimensioning process.

The mentioned problems of block stacking system design set in different contexts and characteristics of the task have been the subject of research and are present in the professional and scientific literatures. The question arises as to their suitability for use in the practical problems encountered by designers and warehouse managers. From that aspect, it would be more convenient to set problems and solutions from the literature in the way that practice sets. Guided by this goal, this paper has the following structure: After the introduction, the formulation of the problem in section two is presented. In the third section, design problems were identified, and an overview of relevant papers was given. In the final section, a concluding comment was given and directions for possible expansion of this work.

2. PROBLEM STATEMENT

The goals of designing the storage area are to provide solutions that make optimum use of available storage space and enable the handling process to run properly. The goal's dominance is defined by the characteristics of the problem to be solved. The goals defined in this way are realized by choosing an appropriate system configuration (layout), which includes determining the block's parameters: lane depth, lane height, and block width. When using a block stacking system for pallet unit load, two basic concepts (layout) can be identified (Đurđević and Pavlov, 2021):

- Block stacking system (Figure 1-a),
- Block stacking system in uniformed storage fields (Figure 1-b).

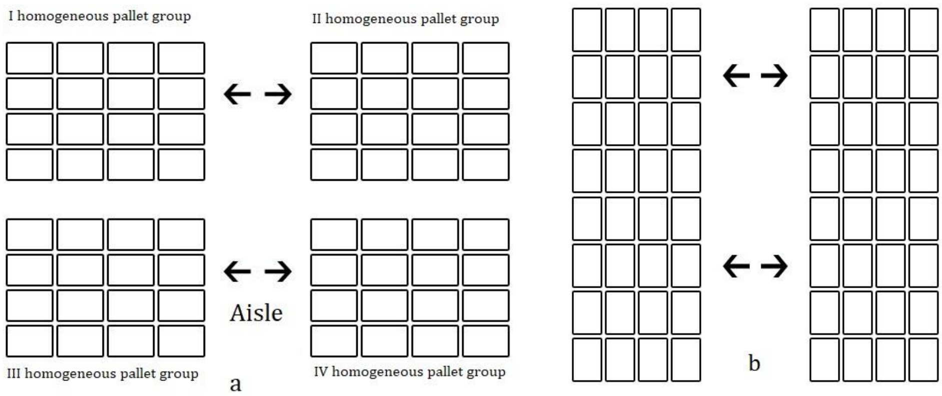

Figure 1 – Block stacking system (a) and block stacking system in uniformed storage fields (b) (Đurđević i Pavlov, 2021)

The surface on which one homogeneous group of pallets is placed in a modified block stacking system (b) represents one lane, or a unified field. Unlike a traditional block stacking system (a), which allows access to pallets in a single group regardless of the level of occupancy in adjacent areas. The pallets are positioned in the field on the wide side in respect to the aisle (to provide access to the handling equipment), which is the main feature of modified block stacking technology (b). When a high number of pallets appear in one homogeneous group, the traditional block system (a) is recommended to ensure the solution's economy without requiring significant additional manipulations. In comparison to the traditional block stacking system (a), the modified block system (b) worse uses space and is typically used when the range of goods is higher, the units of each good in stock are smaller, and the inventory turnover ratio is high (Vukićević, 1995).

In order to prevent the filling of units load or the relocation of pallets, in the case of a random allocation strategy, it is typical to temporarily assign one row to the product that is first stored in that row. Thus, that order is reserved for that product until it is completely emptied, and other (different) products are not allowed to be stored in that order. The application of this principle leads to an effect called honeycombing. There are two types of honeycombing, as it was presented in Figure 2: horizontal and vertical.

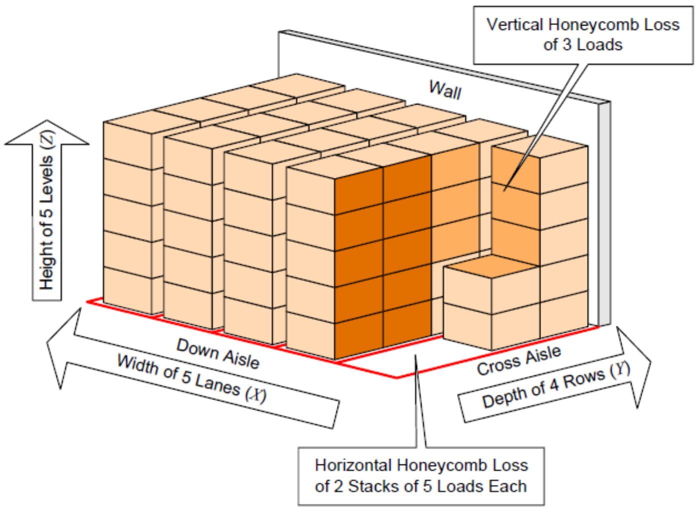

Figure 2 – Stacking pallets in block stacking system (Kay, 2015)

The use of block stacking technology in different task situations has long been a topic of discussion in the literature. The authors have been dealing with this problem for 50 years (one of the first is Kind, 1975). Relevant sources are: (i) Books (Vukićević (1995), Heragu (2008), Tompkins (2010), Bartholdi and Hackman (2014), Rushton (2014), Kay (2015)) and (ii) academic papers (Kind, Marsh, Goetschalckk, Young and Kim, Derhami et al., Venkitasubramony and Adil). In them, the problem of the block stacking system is described, set and solved by applying (explained in the previous part of the paper) different approaches and methods. The following section presents an overview and analysis of only a few (due to space constraints) relevant papers.

3. LITERATURE REVIEW

The analysis of papers or references in the literature will be conducted in a way that connects typical design problems with practical approaches/solutions, as indicated in the paper's goal. A description of typical problems is presented in the first section, followed by an overview and analysis of relevant papers from the literature based on identified problems. Defining the layout, identifying the optimal lane depth, and minimizing relocation of product are all common problems.

3.1 Problem/task description

One of the most important steps in designing a storage area that uses a block stacking system is determining the **layout** for the selected capacity. In this situation, the **optimal lane depth**, number of blocks, number of aisles and cross aisles, stacking height, and other parameters must be determined for the chosen (defined) capacity (Heragu, 2008). During exploitation, tasks for **relocating** specific goods appear to better utilize available space and improve the shipping process' efficiency.

A typical **layout** of block stacking system arrangement consists of numerous blocks (of different depth), each of which includes a few lanes for pallet storage. There are aisles and cross aisles between the blocks where the handling equipment operates. The problem is formulated as the selection of an appropriate block and aisles configuration.

The lane depth of order is the primary dimensioning topic in this paper. Different approaches to solving this problem might be used depending on the technological requirements. The number of pallets that can be placed in the same lane, one after the other, is referred to as lane depth. The number of pallet levels that can be stored on top of each other is determined by lane height, while block width for a group of pallet units is determined by lane depth (the greater the lane depth, the smaller the block width and inversely). The dimension problem can be resolved to choosing the optimal lane depth.

The use of space and the capacity to manage pallets are both impacted by determining the **optimal lane depth**. When individual lanes are very deep (over 10 pallets), the question of whether it is safe to leave one lane of products empty while the lanes next to it are nearly full arises. The entire system's stability may then be endangered. There are two approaches to determine the optimal lane depth: when the calculation is performed for the same goods (the one goods are in all lanes) and when there are a large number of different goods. The characteristics of the incoming and exiting goods flows also impact the lane depth.

The characteristics and features of the requirements that arise determine the dimension of a block stacking system. The emergent form and quantity of technological requirements (TR); the time and place of occurrence and completion of TR; the patience interval; the duration of TR; and the limiting factors influencing the realization of TR are the basic characteristics of TR. Stationarity and non-stationarity, stochasticity-deterministicity, continuity-discontinuity, and homogeneity-inhomogeneity are the features that describe them (Vukićević 1995). The most typical application of block stacking technology is when the relevant characteristic TR is emergent form; that is, when the quantity is such that this technology can be used, and the feature of that characteristic is homogeneity. Additionally, the presence of deterministic related to the requirements for goods handling would characterize a positive situation (by time and quantity). Of course, this is an ideal situation that rarely occurs in reality. There are many situations where the needs are dynamic and change over time.

As previously mentioned, during the operation of a block stacking system, at certain points in time, there are tasks / needs to move certain stocks to make better use of available space and improve the efficiency of the shipment process. This is present when storage and retrieval times of inventories are uncertain and storage space for inventories is limited. The task is to allocate inventories (units of cargo) to storage areas so that the total expected number of **relocations** is minimized (Yang & Kim (2006)).

3.2 Literature

This chapter is giving short literature review of some papers that deal with relevant research related to this topic. Table 1 summarized some of them.

Table 1 shows a review of the literature with previously identified problems.

Problems	References	Goal	Methods
(P1)- determining the optimal lane depth	Kind, D. A. (1975)	space utilization	analytical methods
	Marsh, W. H., & WH, M. (1979)	space utilization	analytical methods and simulations
	Goetschalckx, M., & Donald Ratldff, H. (1991)	space utilization	dynamic programming and heuristics
	Derhami, S., Smith, J. S., & Gue, K. R. (2017)	space utilization and accessibility	analytical methods
	Derhami, S., Smith, J. S., and Gue, K. R. (2019)	space utilization and accessibility	analytical methods and simulations
	Venkitasubramony, R., & Adil, G. K. (2019a)	space utilization	scenario based model
	Venkitasubramony, R., & Adil, G. K. (2019b)	space utilization and material handling costs	Analytical methods and computational experiments
(P2)– determining the layout of block stacking system	Derhami, S., Smith, J. S., & Gue, K. R. (2019)	space utilization and accessibility	analytical methods and simulations
	Derhami, S., Smith, J. S., & Gue, K. R. (2020)	space utilization and accessibility	simulations
(P3)- Relocation goods	Yang, J. H., & Kim, K. H. (2006)	Minimizing relocation	dynamic programming

Kind (1975) presented one of the earliest papers on determining the optimal lane depth, and because of its historical relevance, a more extensive description was offered. Letting

Q, w, and z denote the lot size in pallet loads, width of aisle (in pallet stacks), and stack height in pallet loads, respectively, his formula (1) determines the near optimal lane depth, d, as:

$$d = \sqrt{\frac{Q*w}{z}} - \frac{w}{2} \text{[number of pallets]} \qquad (1)$$

He suggests a simple formula to determine a near - optimal lane depth, under these standard assumptions: (i) goods are allocated to storage spaces using the random storage operating policy, (ii) replenishment (in predetermined lot sizes) is instantaneous and done only when the inventory excluding safety stock has been completely depleted, (iii) lots are rotated on a first-in first-out basis, (iv) withdrawal of lots takes place at a constant rate, and (v) an empty lot is available for use immediately. The model is limited as a function of these assumptions, but it served as a foundation for other authors who enhanced the model by eliminating some assumptions.

Marsh (1979) dealt with the similar problem of lane depth determination. He evaluated space utilization for different variants of lane depth and storage policy using simulation.

Goetschalckx and Ratliff (1991) focused on the problems of determining the lane depth in two scenarios: (i) when the goods are homogeneous in one lane, and (ii) when the goods are inhomogeneous in one lane. The primary goal was to reduce the amount of storage space necessary. They used a dynamic programming approach to determine the optimal lane depth and heuristics to compare the results.

Derhami, S., Smith, J. S., & Gue, K. R. (2017) discussed the problem with block stacking technology in several papers (Derhami et al 2017, Derhami et al 2019, Derhami et al, 2020). They developed formulas for different characteristics of technological requirements in their paper (Derhami et al, 2017). They observed situations in which the delivery and dispatch intensities to and from the warehouse are known, and situations in which the delivery intensity is known but the dispatch is not. By determining the appropriate lane depth, they aimed to reduce the honeycombing effect. They also included a graphical method as an aid for addressing the problem (Figure 3).

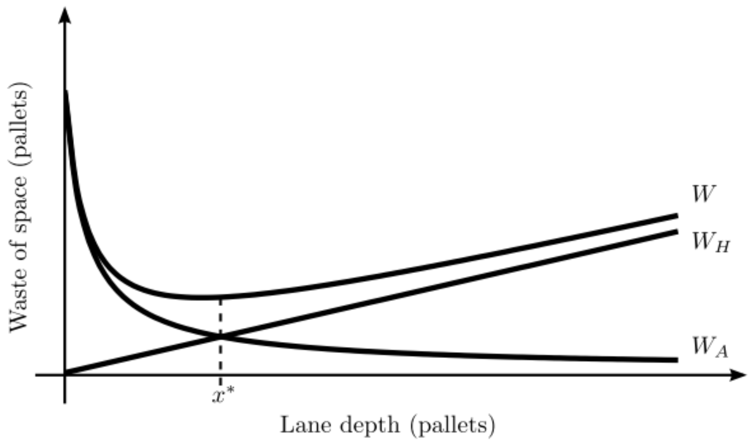

Figure 3 – Graphical method for determining lane depth

The diagram in Figure 3 can also be used to determine the optimal lane depth. The depth is determined using data from the honeycombing effect (W_H) and the area of aisles (W_A). The optimal lane depth was found at the intersection of these two curves. The honeycombing effect glans with lane depth, and the area of the occupied by aisles reduces, and inversely. The average loss of storage capacity is determined in cross section these two curves (Derhami et al, 2017). The optimal lane depth is reached when this loss (W) is the smallest. Authors of three cases that were observed:

1) Supply (P) and demand (λ) are both constant and deterministic (Formulas 2 and 3),

2) Supply (P) exceeds demand (λ), which is both constant and deterministic (Formulas 4 and 5),

3) The supply (P) is smaller than the demand (λ), which is stochastic and not constant (Formulas 6 and 7),

suggest the following formulas (2-7):

$$x^* \approx \sqrt{\frac{Q*a}{2*z}} \tag{2}$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{c_i}\right)*Q_i}{2*\sum_{i=1}^{n} e_i*h_i}} \tag{3}$$

$$x^* \approx \sqrt{\frac{a*(Q*(P-\lambda)-2*\lambda)}{2*z*P}} \tag{4}$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{z_i*P_i}\right)*(Q_i*(P_i-\lambda_i)-2*\lambda_i)}{2*\sum_{i=1}^{n} e_i*h_i}} \tag{5}$$

$$x^* \approx \sqrt{\frac{a*(Q-z)*(\lambda-P)}{2*z*\lambda}} \tag{6}$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{z_i*\lambda_i}\right)*(Q_i-2)*(\lambda_i-P_i)}{2*\sum_{i=1}^{n} e_i*h_i}} \tag{7}$$

x^*- optimal lane depth for single SKU (in unit of pallet)

x^*_C- optimal common lane depth for multiple SKUs (in unit of pallet)

Q- production (arrival) batch quantity (in units of pallet)

a- aisle width (in units of pallet)

z- stackable height (in units of pallet)

e- clear height of the warehouse (in units of pallet)

h- height of a pallet of a SKU (in unit of distance i.e., inch, cm)

P- production rate (in units of pallet/time)

λ- depletion rate (in units of pallet/time)

Derhami, S., Smith, J. S., & Gue, K. R. (2020) focused their research on dimensioning and designing warehouse layout. The simulation method was used in the situation of dynamic solving systems. To run the program, authors first define all the possible scenarios (layouts). Because there are several scenarios depending on size of the warehouse, some limits must be established. The minimum and maximum number of aisles, as well as cross aisles, reflect these limits. The optimal lane depths (formula 9), the number of aisles, and the number of cross aisles is determined first, and then the deviations in relation to that number are defined. For all goods stored, it is assumed that the lane depth is constant (formula 8). The formulas are as follows:

$$\overline{x^*} = \frac{S^l - n_a^* * A}{2 * n_a^*} \tag{8}$$

$$n_a^* = \sqrt{\frac{S^l * N_s}{4 * S^w * A}} \tag{9}$$

It is necessary to introduce the following notation to make the used formulas more understandable:

$\overline{x^*}$ - optimal common bay depth (in units of pallets)

S^l – warehouse length (in units of pallets)

n_a^* - optimal number of aisles

A- aisle width (in units of pallets)

N_s – number of SKUs stored in warehouse

S^w – warehouse width (in units of pallets)

Venkitasubramony, R., & Adil, G. K. have addressed the determination of lane depth, number of aisles, and cross aisles in block warehouses stacking system in several papers Venkitasubramony, R., & Adil, G. K. (2019a), Venkitasubramony, R. and Adil, G. K. (2019b and Venkitasubramony, R. and Adil, G. K. (2021)). Venkitasubramony, R., and Adil, G. K. (2019a) used the scenario tree methods in their research. The basis for wood is the monthly average demand for products. The tree branches out from that node to the number of branches in the relevant months. Further branching to potential possibilities relating to the next month is performed from each branch (which represents a certain month). This branching continue till the final month arrives. Each branch combination represents a single scenario, with a probability of occurrence assigned to each branch. The final probability for each scenario is calculated using the individual's product, based on which the final ranking of the alternatives is performed, and the storage capacity is defined. The analytical method is used to obtain additional characteristic dimensions.

They're searching for a solution that will work in different ~~of~~ situations. The Robust Design Model is the model which they use. It intends to minimize overstocking's expected costs, risks, and costs. The lane depth, the number of lanes in the main warehouse, and the capacity necessary for renting are all considered factors in this model. The following notation must be introduced to better understand the goal function:

$x = [x_1, x_2]$- x_1 – lane depth (in pallets), a x_2 – number of lanes

y_m- additional warehouse capacity hired during a month m

g- the total expected space cost

λ- risk aversion parameter

ω- overflow penalty coefficient

OF- inventory surge

With limitations (11)– (12), the objective function (formula 10) is defined to minimize storage costs, capacity shortage costs, and capacity shortage risk (13).

$$F = g * (x, y_1) + \lambda * RISK(x, y_1) + \omega * OF(x, y_1) \rightarrow min \tag{10}$$

$$[x_{1(min)}, x_{2(min)}] \leq [x] \leq [x_{1(max)}, x_{2(max)}] \tag{11}$$

$$[y_{1(min)}] \leq [y_1] \leq [y_{1(max)}] \tag{12}$$

$$x_1, x_2 \in Z^+ \tag{13}$$

Restriction (11) relates to keeping the lane depth and number of lanes within a certain range, while restriction (12) refers to keeping the leased capacity within a certain range. The fact that both the lane depth and the number of lanes are given in integers is constraint (13) (in the number of pallets).

Yang and Kim (2006) explored at how to schedule goods in a block stacking system while reducing unit relocation during storage. They used several criteria and suggested that once a unit was transferred, no more relocations were required. When many diverse elements are stored in one lane, relocation occurs. When shipping one of them that is covered by other objects, the items must be relocated until the ones that are required are find. This problem is usual and difficult to research. As a result, he is entitled to greater research space.

4. CONCLUSION

For the warehouse to be profitable, the utilization of space in it must be at a satisfactory level. To achieve that, it is necessary to adequately designing the storage area. One of several technologies used in warehouse is the block stacking system. Although it is the oldest known technology, it is still in use due to its good characteristics. The advantage of this technology in relation to competitors (racks) is reflected in the fact that it is very simple, flexible, easily adapts to new requirements. With minimal costs (if space allows), the number of rows or the depth of block stacking can be increased relatively easily. The dimensioning method is of great importance for the efficiency of applied block stacking technology solutions.

The main goal of the paper was to connect the works from the literature with real practical problems that designers-engineers encounter when designing a block stacking storage. An overview of relevant works/papers was given for the identified group of design problems. Due to space limitations, some characteristic works/papers and models were presented in more detail, with the devoted on determining the optimal lane depth. The presented models can serve as a useful support to engineers in dimensioning the relevant parameters of the block stacking storage.

One of the extensions of this paper could be the application and testing of selected models from the literature on real problems from practice (e.g. case study). The characteristics of a specific task would guide the selection and application of appropriate approaches-models from the literature.

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PALLETE SELECTION ACCORDING TO THE MATERIAL TYPE USING THE EDAS METHOD

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Abstract: *Although the pallet may not receive much attention, it plays a significant role in the supply chain. Palletization is one of the most commonly used methods for uniting products and transporting stored goods safely and effectively in many industries. Nowadays, there are different types of pallets, that vary in dimensions, the material they are made of, their shape and usage characteristics. Each pallet type has its advantages and disadvantages, which should be considered when choosing the appropriate one.*
This paper is about the selection of the pallet type according to their raw material, in terms of logistics requirements for cost-effectiveness, durability and resistance to external influences and ecology requirements for recyclability and have the lowest negative impact on the environment. Wooden, plastic and cardboard pallets were evaluated using the multi-criteria decision-making method EDAS.

Keywords*: Pallets, Packaging, EDAS, Ecology, Logistics*

1. INTRODUCTION

As an integral part of supply chains, packaging enables efficient storage and transportation with minimum costs and delivery times, along with maximum protection of goods on their way from the manufacturer to the end consumer. In addition, the packaging is one of the most important segments of logistics in terms of environmental protection, since one of the main environmental problems is the disposal, recycling and processing of waste material used for packaging. One of the most commonly used methods of unitizing products to safely and effectively move and store goods through the supply chain is pallets.

Nowadays, hundreds of different types of pallets are in use, which differ in dimensions, material from which they are made, shape, and exploitation characteristics. Pallets are usually wooden, but they can also be made of other materials such as plastic, metal (usually aluminium and steel), cardboard and recycled materials.

Among various pallet types, wooden pallets dominate the market share. Plastic pallets are in second place. Besides that, compressed cardboard pallets, also known as "eco-pallets", are often used for light loads, where recycling and easy disposal is crucial (Bengtsson and Logie, 2015).

Wooden, plastic and cardboard pallets all have advantages and disadvantages, although it is essential to consider various criteria when deciding which pallet to use for transporting goods. Multi-criteria decision making (MCDM) methods could be used for solving such problems when multiple criteria ought to be considered together.

The EDAS method is very effective when conflicting criteria exist in the MCDM problem (Ecer, 2017). Therefore, considering the requirements in terms of logistics and ecology, the EDAS method is used for this study. Decision making in this paper will focus on wooden, plastic and cardboard pallets with the dimension of 1200 mm × 800 mm, the most widely used type of pallets in Europe, also known as EUR pallets.

This paper aims to build an effective decision tool to evaluate the performance and environmental impact of the pallets and determine the best pallet option. The remaining part of the paper is outlined in the following manner: A brief literature review including various studies focused on environmental impact in Section 2. The EDAS method calculation steps are presented in Section 3. Alternatives, criteria and results of the proposed method are illustrated in Section 4. The conclusion of the following study is given in the last section of the paper.

2. LITERATURE REVIEW

Most studies focused on comparing wooden and plastic pallets through their environmental impact. Kočí (2019) analysed the environmental impact of wooden pallets, primary plastic pallets, and secondary plastic pallets. The results of this study indicate that wooden pallets have a better environmental impact than primary and secondary plastic pallets if energy recovery occurs. Additionally, the study showed that the weight of the pallet plays a significant role in its total environmental impact.

Much of the available literature deals with the question of life cycle assessment (LCA) as one of the environmental management techniques that "addresses the environmental aspects and potential environmental impacts throughout a pallet's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal (Khan et al., 2021). Ma et al. (2020) in their study compared the life cycle performance of treated wooden and plastic pallets through a detailed cradle-to-grave life cycle assessment (LCA). The results recommend that wooden pallets have a lower overall carbon footprint than plastic pallets during their life cycle.

Likewise, Deviatkin et al. (2019) investigated the carbon footprint of a EUR-sized pallet made of wood or plastic using data from previously published literature. According to the results, the production of wooden pallets has a lower impact on climate change than plastic pallets, due to the relatively low impact of wood harvesting and the biogenic nature of the wood (Khan et al., 2021).

The environmental impact of a wider range of pallet types according to the raw material was analysed by Bengtsson and Logie (2015). In their study, they compared the environmental impacts of softwood, hardwood, plastic, and cardboard pallets for one-way use and in producing pooled pallet systems in either China or Australia. The results showed that the use of wood along with regular maintenance has the minimum environmental impact among all types of studied pallets.

In addition, no research has been found that surveyed which pallet type, based on its raw material, is the best alternative considering requirements of logistics and ecology at the same time.

3. EDAS METHOD

Evaluation based on Distance from Average Solution (EDAS) is a multi-criteria decision-making method proposed by Keshavarz Ghorabaee et al. in 2015. In the EDAS method, the alternatives to an MCDM problem are evaluated based on positive and negative distances from an average solution. An alternative which has higher values of positive distances and lower values of negative distances from the average solution is a more desirable alternative according to this method (Ecer, 2017).

Assuming n alternatives and m criteria, the steps for implementation of multi-criteria decision making according to the EDAS method are as follows:

Step 1: Building a decision matrix based on the following formula

$$X = \left[x_{ij}\right]_{mxn} = \begin{bmatrix} x_{11} & \dots & x_{1n} \\ x_{21} & \dots & x_{2n} \\ \vdots & \dots & \vdots \\ x_{m1} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

Where: m is the number of alternatives, n is the number of criteria, x_{ij} is the value of criterion j at option i.

Step 2: Determining an average solution according to all criteria, shown as follows:

$$x_j{}^* = (x_1{}^*, x_2{}^*, \dots, x_m{}^*)$$
(2)

Where:

$$x_j{}^* = \frac{\sum_{i=1}^{m} x_{ij}}{m} = \left(\frac{\sum_{i=1}^{m} x_{i1}}{m}, \frac{\sum_{i=1}^{m} x_{i2}}{m}, \dots, \frac{\sum_{i=1}^{m} x_{im}}{m}\right) = (x_1{}^*, x_2{}^*, \dots, x_m{}^*) \quad (3)$$

Step 3: Defining positive distance (PD) and negative distances (ND) from an average solution.

$$PD = \left[pd_{ij}\right]_{mxn} \quad (4)$$

$$ND = \left[nd_{ij}\right]_{mxn} \quad (5)$$

These values should be determined concerning the benefit or cost type of criteria.

If a *j*th criterion is a benefit criterion, then positive distance $pd_{ij}{}^+$ is calculated as

$$pd_{ij}{}^+ = \frac{\max(0,(x_{ij} - x_j{}^*))}{x_j{}^*}, \text{j} \in \Omega_{max} \quad (6)$$

If a *j*th criterion is a benefit criterion, then negaitive distance $nd_{ij}{}^+$ is calculated as

$$nd_{ij}{}^+ = \frac{\max(0,(x_j{}^* - x_{ij}))}{x_j{}^*}, \text{j} \in \Omega_{max} \quad (7)$$

If a *j*th criterion is a cost criterion, then positive distance $pd_{ij}{}^-$ is calculated as

$$pd_{ij}{}^- = \frac{\max(0,(x_j{}^* - x_{ij}))}{x_j{}^*}, \text{j} \in \Omega_{min} \quad (8)$$

If a *j*th criterion is a cost criterion, then negaitive distance nd_{ij}^{-} is calculated as

$$nd_{ij}^{-} = \frac{\max(0,(x_{ij} - x_j^{*}))}{x_j^{*}}, \text{j} \in \Omega_{min} \quad (9)$$

Step 4: Determine the weighted sum of *PD* and *ND* for all alternatives, shown as follows:

$$SP_i = \sum_{j=1}^{n} W_j \, pd_{ij} \text{ , } i = 1,\ldots,m; \quad (10)$$

$$SN_i = \sum_{j=1}^{n} W_j \, nd_{ij} \text{ , } i = 1,\ldots,m; \quad (11)$$

where w_j is the weight of the criterion *j*.

Step 5: Normalize the SP and SN values according to the formula.

$$NSP_i = \frac{SP_i}{max_i\,(SP_i)} \text{ , } i = 1,\ldots,m; \quad (12)$$

$$NSN_i = 1 - \frac{SN_i}{max_i\,(SN_i)} \text{ , } i = 1,\ldots,m; \quad (13)$$

Step 6: Calculating appraisement score (AS_i) based on each alternative's NSP_i and NSN_i:

$$AS_i = \frac{1}{2}\,(NSP_i + NSN_i) \text{ , } i = 1,\ldots,m; \quad (14)$$

where $0 \le ASi \le 1$.

Step 7: Ranking the alternatives according to the calculating results of AS. The alternative with the highest AS_i is considered the best choice among the candidate alternatives.

4. PALLETS CLASSIFICATION

Specific requirements of the customers determined a large diversity in pallet type. Wood is the most common material due to its low market price and low investments needed to manufacture wooden pallets. Plastic pallets are also widely used. However, their use depends on industry-specific requirements, such as the medical industry, which sets specific hygiene standards. Furthermore, due to the lack of standards on plastic pallets, their dimensions vary significantly, though they often conform to the dimensions of the wooden pallets (Deviatkin et al., 2019). Cardboard pallets are much lighter weight and completely recyclable alternative to wooden pallets. On the other hand, cardboard pallets are not convenient for heavyweight products. What is more, they are vulnerable to moisture, which restricts their use.

The performance of the investigated pallets, expressed by their carrying capacity, the number of cycles or an expected lifetime, varied in the studies investigated. The carrying capacity of the investigated pallets was rarely given. For the wooden pallet, a load capacity of 453-1350 kg was given, depending on the management strategy, 1000 kg or 1500 kg (Deviatkin et al., 2019). For the plastic pallet, a higher load capacity of 1500 kg or 1810 kg has been indicated (Kurisunkal, 2010). According to various manufacturers, cardboard pallets are strong enough to carry up to 750 kg (European Commission, 2022; Pallite, 2021)

Following cost information obtained from various companies on the European market cardboard pallets cost between 4,79 euros and 11,74 euros, while wooden pallets cost from 5,09 euros to 30,19 euros and plastic from 12,49 euros to 62,47 euros (Kite Packaging, 2022; MyPalletsOnline, 2022; New wooden pallets Archieven, 2022).

The lifespan of a pallet depends on many factors, including the raw material type, manufacturing process, number of handlings, the type of machinery used for handling, maintenance services and others (Ma et al., 2020). Cardboard pallets are usually intended for one-way use. In contrast, wooden and plastic pallets are more durable. Wooden pallets were usually modelled to be used for 5 to 30 cycles, while they occasionally perform up to 90 cycles (Deviatkin et al., 2019). Plastic pallets are assumed to have longer service lives than wooden pallets, which would last for 50–100 cycles. Shorter life of five cycles and longer life of 300 cycles were also considered. The longer service life of plastic pallets is due to their higher strength and better resistance to weathering (Ma et al., 2020). On the other hand, plastic pallets cannot be repaired, unlike wooden pallets, thus requiring better handling conditions to ensure a long life (Deviatkin et al., 2019).

Cardboard pallets can be recycled into new cardboard products or eventually into new pallets. One of the essential tools for the European Union's transition toward a circular economy is waste recycling. Eurostat (2019) reports that 82% of all corrugated cardboard packaging is recycled.

One of the possibilities for recycling wood and plastic waste is to utilise it to produce a composite product. According to Eurostat (2019), 31,1% of wooden packaging and 40,6% of plastic packaging is recycled. The industrial EUR 1 pallet can never be fully recycled into a new pallet. In most cases, parts of used wooden pallets are mulched into chips which can be pressed into wooden blocks to make parts of a new pallet. They can also be used to repair damaged pallets or turned into pulp for paper production. However, due to the complex nature of wooden pallet recycling, we argue that they are rarely recycled and more often than not end up in landfills (KraftPal Ltd., 2020). After they are retired, plastic pallets are dismantled to HDPE (High-Density Poly Ethylene), which will then be recycled to make various articles including certain lighter-use pallets and slip sheets and several other components of the pallet (Ma et al., 2020). The production of plastic pallets is an energy-intensive process, even though they are lighter than wooden pallets. On average, the production of a wooden pallet has a partial carbon footprint of 5.0 kg CO_2-eq, while the manufacturing of a virgin plastic pallet releases 62 kg CO_2-eq (Deviatkin et al., 2019). The production of cardboard pallets releases 2,39 kg CO_2-eq. (KraftPal Ltd., 2020).

4.1 PALLET SELECTION CRITERIA

The key criteria that influence managers' decisions on which pallet type to use for transporting goods are identified in this section. Based on the logistics and ecology requirements of pallets six criteria were considered in this study. The logistics criteria include strength, price and durability, while the environmental criteria include recyclability, carbon footprint in transport and carbon footprint in production. These criteria are defined as follows:

Strength (C1) is a term that refers to the load-carrying capacity of the pallet throughout the shipping environment. The construction of the pallet must be strong enough to carry the required load, therefore strength is a benefit criterion.

Price (C2) is usually one of the main criteria that often receives more attention than the other factors. It is important to strike a balance between the price of the pallet and the value of the product delivered to the end customer undamaged. Hence, price is a cost criterion.

Durability (C3) is a term which will be used to refer to the ability of pallets to withstand the rigours of the shipping and handling environments. This criterion is based on the lifespan of a pallet which is usually expressed as a number of cycles.

The packaging regulations require organisations to minimise the materials they introduce into the packaging supply chain and promote the reuse, recovery, recycling, composting or biodegrading of materials (White and Wang, 2014; Zhang and Zhao, 2012). In this case, the environmental criteria include recyclability. Recyclability (C4) is the capability of packing material to be reused in manufacturing or making another item. In order to compare pallets in this study, Eurostat (2019) reports the recycling rate of packaging waste by the type of packaging have been used.

Transport has a significant impact on the environment due to the high fuel consumption (Ma et al., 2020). Moreover, the fuel consumption depends on the amount of cargo transported. Considering the different weights of the pallets, the environmental criteria include carbon footprint in transport.

Carbon Footprint in transport (C5) is expressed as the total carbon dioxide (CO_2) emissions per pallet released during transport. These values will be calculated in section 4.2

Carbon Footprint in production (C6) refers to total carbon dioxide (CO_2) emissions released during pallet production.

4.2 Calculation of CO_2 emissions in transport per pallet

The values of this criteria for each alternative have been calculated using the formula:

$$CO_2 emissions = EF * FC * KM \tag{15}$$

Where: EF is the emission factor (in kg CO_2/litre), FC is the fuel consumption (litre per km) and KM is the total distance performed by a vehicle (km).

The formula for calculating the emissions in this model is obtained on the basis of the fact that it represents the sum of the total distance performed by the vehicle, the fuel consumption and the emission factor (Rizet et al., 2012). In this calculation total distance is 100 km. The emission factor depends on the type of fuel. The vehicle used for this paper uses diesel, therefore emission factor is 2,7 kg CO_2/litre (International Post Corporation, 2018).

The FC equation represents the fuel consumption for transporting a particular load to the vehicle, and FCpr and FCpu the fuel consumption when the vehicle is empty and when it is full (Hosseini and Shirani, 2011).

$$FC = FCpr + (FCpu - FCpr) * LF \tag{16}$$

Based on this equation, it can be concluded that fuel consumption does not increase linearly with the increase in the amount of cargo being transported. When the vehicle is fully loaded, the fuel consumption is about 40 l/100 km and when the vehicle is empty it is about 28 l/100 km in all three scenarios (according to the specifications of the Scania truck).

The load factor (LF) is expressed as a percentage of capacity in tonnes. Equation (17) is used to define the load factor.

$$LF = TON/CAP \tag{17}$$

Where: TON is the average load (tonnes) and CAP is the maximum transport capacity of the vehicle (tonnes).

The weight of the pallet depends on its raw material. The approximate weight of a wooden EUR pallet is 25 kg, according to the European Pallet Association (Deviatkin et al., 2019). The average mass of the plastic EUR pallet equals 20 kg (Deviatkin et al., 2019). Cardboard pallet weights 4.5 kg, according to the data from manufacturers (KraftPal Ltd., 2020). In order to compare CO_2 emissions in transport per pallet for each alternative, it is considered that the average load is calculated as 33 EUR pallets. The same goods are loaded on each pallet, with a weight of 500 kg, according to the maximum capacity of material handling equipment (LLM Handling Equipment Ltd, 2022).

Table 1 shows the results of CO_2 emissions in transport per pallet alternative.

Table 1. CO_2 emissions per pallet calculation

	Wooden pallet	Plastic pallet	Cardboard pallet
Pallet weight (kg)	25	20	4.5
The total weight (kg)	17325	17160	16648.5
LF - load factor	0.433	0.429	0.416
FC - fuel consumption (l/100km)	33.198	33.148	32.995
The total CO_2 emissions (kg)	89.633	89.500	89.085
CO_2 emissions per pallet (kg)	2.716	2.712	2.700

4.3 Results of calculation steps and ranking of EDAS method

This problem considers six criteria, which were equally weighted and taken as $w_1=w_2=w_3=w_4$ $w_5=w_6 = 0.167$. Wooden, plastic and cardboard EUR pallet are alternatives. Strength, Durability and Recyclability are beneficial criteria and Cost, Carbon footprint in transport and Carbon footprint in production are non-beneficial.

Based on the quantitative data from literature and research presented in section 4.1 of this paper, the decision matrix is given in Table 2.

Table 2. The decision matrix

Alternatives	Criteria					
	C1 - Strength	C2 - Cost	C3- Durability	C4 - Recyclability	C5 - Carbon footprint in transport	C6 - Carbon footprint in production
A1 – Wooden pallet	1500	30.19	30	31.1	2.716	5
A2 – Plastic pallet	1810	62.47	100	40.6	2.712	62
A3 – Cardboard pallet	750	11.74	1	82	2.700	2.39
	MAX	MIN	MAX	MAX	MIN	MIN
x_j^*	1353.333	34.800	43.667	51.233	2.709	23.130

The corresponding average solution x_j^* for all evaluation criteria is calculated for step 2 which can be seen in the last row of Table 2.

Positive distances (*PD*) and negative distances (*ND*) from an average solution, calculated for step 3, are given in Table 3.

Table 3. Positive and negative distances from an average solution

	pd_1	pd_2	pd_3	pd_4	pd_5	pd_6	nd_1	nd_2	nd_3	nd_4	nd_5	nd_6
A1	146.667	0.000	0.000	0.000	0.007	0.000	0.000	4.610	13.667	20.133	0.000	18.130
A2	456.667	27.670	56.333	0.000	0.003	38.870	0.000	0.000	0.000	10.633	0.000	0.000
A3	0.000	0.000	0.000	30.767	0.000	0.000	603.333	23.060	42.667	0.000	0.010	20.740

The results of the remaining steps (4 to 7) and the ranking of pallets are given in Table 4.

Table 4. The results of calculation steps and ranking of the EDAS method

	SP_i	NSP_i	SN_i	NSN_i	AS_i
A1	24.494	0.253	9.442	0.918	0.586
A2	96.784	1.000	1.776	0.985	0.992
A3	5.138	0.053	115.198	0.000	0.027

Based on the results obtained through the analysis based on the EDAS method, the ranking of pallets is derived as 2-1-3, concerning equal criteria weights. Consequently, the results show that the best option is plastic pallets with an AS of 0.992. The wooden pallet with an AS of 0.586 is second-ranking and the cardboard pallet with an AS of 0.027 is the worst option.

5. CONCLUSION

Selecting the suitable pallet type is a difficult MCDM problem associated with complexity and uncertainty. What is more, in order to measure pallet performance, it is important to consider both logistics and environmental impact.

This paper aims to build an effective decision tool to evaluate the performance and environmental impact of the pallets and determine the best pallet option. Therefore, the EDAS method was applied to rank wooden, plastic and cardboard EUR pallets. The results show that plastic pallets are the best solution according to the chosen criteria.

Despite the various advantages outlined in the paper, these results are subject to certain limitations, which imply some fruitful directions for future research. For instance, the weighting estimation of the decision criteria is equal. One future research direction is to show how the rank order of pallets behaves when the criteria priority weight changes. Furthermore, data are based upon literature and manufacturers' specification. This study can be helpful for further research, for instance, more interchangeable scenarios will show different results for all three pallet types. It will also help to compare other pallet types that are already in the market or are planned to come into the market.

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FORKLIFT SELECTION USING AN INTEGRATED CRITIC-MARCOS MODEL

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Abstract: *In modern logistics processes, forklifts represent one of crucial means for performing handling operations. As a result, they play a very important role in achieving the overall efficiency of logistics systems. Based on the research conducted in the warehousing system of the Natron-Hayat company, and taking into account the current needs of the company, experience and knowledge of managers as decision-makers in this warehouse, criteria and alternatives for selecting a forklift were defined. The objective CRITIC (Criteria Importance Through Intercriteria Correlation) method was used to determine the significance of the criteria, while the MARCOS (Measurement of Alternatives and Ranking according to Compromise Solution) method was used to evaluate and select the most favorable forklift. By analyzing the collected data using the MARCOS method, it was obtained the ranking of alternatives, according to which the A4 forklift is the most favorable alternative, and the A1 forklift is the worst alternative. The obtained results have been verified through sensitivity analysis, which includes changes in weight criteria, as well as comparative analysis with other methods of multi-criteria decision making.*

Keywords*: forklifts, warehouse, multi-criteria decision making, CRITIC, MARCOS*

1. INTRODUCTION

Logistics as an area is becoming increasingly important every day by rationalization and optimization activities improving the whole business and the overall effect of the supply chain. In addition to transport, which is the greatest cause of logistics costs, as a very important element or subsystem of logistics, there is a warehousing subsystem with all the accompanying activities. Taking into account that the movement of goods is a dominant activity in a modern warehousing system, the processes become more complex, so it is necessary to create different models for decision-making. This paper analyzes the warehousing system of the Natron-Hayat company as well as the possibility of purchasing another forklift to perform handling operations. Through the overall research, and this paper is a part of it, the parameters of queues on two transshipment fronts in the warehousing system were calculated in the first phase, and

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it was determined that Natron-Hayat achieves satisfactory results with two existing transshipment fronts. In the next phase of work, the efficiency of transport and handling equipment in the company's warehousing system was calculated, and the DEA method was applied to determine the efficiency of a total of eight forklifts operating in the Natron-Hayat warehousing system. Since the DEA method showed insufficient discriminatory power to determine the overall efficiency of all eight forklifts, the MCDM model was further applied. The final phase of the work is a part of the research presented in this paper. After determining which forklift is the most efficient in the warehousing system, it was started the procurement of an additional forklift according to the needs and appropriate criteria in this warehousing system. To analyze the collected data, it was used an integrated multi-criteria model: CRITIC-MARCOS. The CRITIC method is an objective MCDM method which was applied to calculate weight coefficients used then in the MARCOS method to weight the initial values.

MCDM methods, as a widely applicable tool in various areas of business decision making, have been applied in this paper for the purpose of decision making in the procurement of forklifts. Observing a large assortment of forklifts with different characteristics, the paper analyzes nine criteria that are of great importance for the selection when buying forklifts. By research in the warehousing system of the company, and taking into account the experience and knowledge of managers in this warehouse, the criteria and alternatives for forklift selection were defined. Analyzing four potential forklifts that represent potential alternatives, it is necessary to define the best one. An objective CRITIC method was used to determine the significance of the criteria, while the MARCOS method was used to evaluate and select the most favorable forklift. The obtained results have been verified through sensitivity analysis, which includes changes in weight criteria as well as comparative analysis with other methods of multi-criteria decision making.

Through this paper, it is necessary to first define the criteria and alternatives needed to purchase a forklift, the next step involves the application of the CRITIC method to define the weights of the criteria, and then the application of the MARCOS method to determine the most efficient forklift. At the very end, it is important to perform a sensitivity analysis as well as a comparative analysis in order to determine the stability of the results and obtain the most favorable solution.

2. BRIEF LITERATURE REVIEW

The current warehousing system of the company is decentralized, Mulalić et al. (2017a), Mulalić et al. (2017b), where each production facility has its own warehouse. In such conditions, there is an accumulation of requests for loading goods into means of transport and waiting in line, which in turn incurs certain costs. According to Stević (2015), in order to assess the quality of the functioning of the warehousing system and processes in it, it is necessary to define key performance indicators in a specific logistics subsystem. The company concerned is a company with production as a main activity, but which also has a warehousing system within its complex, which has proven to be part of the company representing a potential place for improving performance. After the measurement of key performance indicators based on the method of comparing values, measures for possible improvement, further measurement and monitoring of performance are given, which is one of the prerequisites for successful and efficient logistics subsystem operations. However, this paper is an upgrade to the paper by Mahmutagić et al. (2021), in which it was developed the DEA-MCDM model, which refers to determining the efficiency of present forklifts in the Natron-Hayat company.

Multi-criteria decision-making methods are increasingly applied in all spheres of logistics. Although, in this paper, the focus is on forklift selection to serve in the warehousing system, MCDM methods are also applied to select the warehouse location according to Ulutaş et al. (2021). This study proposes an integrated gray MCDM model to determine the most appropriate location of a supermarket warehouse, where five alternatives were evaluated with twelve criteria. In the paper by Amin et al. (2019), the AHP and TOPSIS methods were applied to determine the best pallet placement in storage racks. In addition, a large number of studies have been published in the field of transport, such as the paper by Yannis et al. (2020) concluding that MCDM methods are used mainly to assess transport options rather than transport policies or projects, and the most commonly used MCDM method in transport sector problems is the AHP method (Tadić et al., 2013; Tadić et al., 2015). According to Mardani et al. (2016) where various studies were analyzed, it was concluded that, within transport, ranking the quality of service was the first area of application of MCDM, and the aviation industry was ranked as the first transport infrastructure to apply MCDM methods. In the paper Đalić et al. (2021), using a MCDM method, it was developed a model for selecting the best strategy in a transport company by which this company seeks to improve business.

3. METHODOLOGY

In this section of the paper, Figure 1 presents the methodology applied to select a forklift using an integrated CRITIC-MARCOS model. The research methodology in this paper consists of three phases. The first phase refers to the definition of criteria and alternatives for the forklift selection. In the second phase, it is applied multi-criteria decision-making, which includes three steps, namely: application of CRITIC method for defining criterion weights, then application of MARCOS method for determining the most efficient forklift, and sensitivity analysis of results obtained. The last step of the third phase is the sensitivity analysis of the results obtained. In the third phase of work, the results of all applied steps are aimed at determining the most favorable forklift.

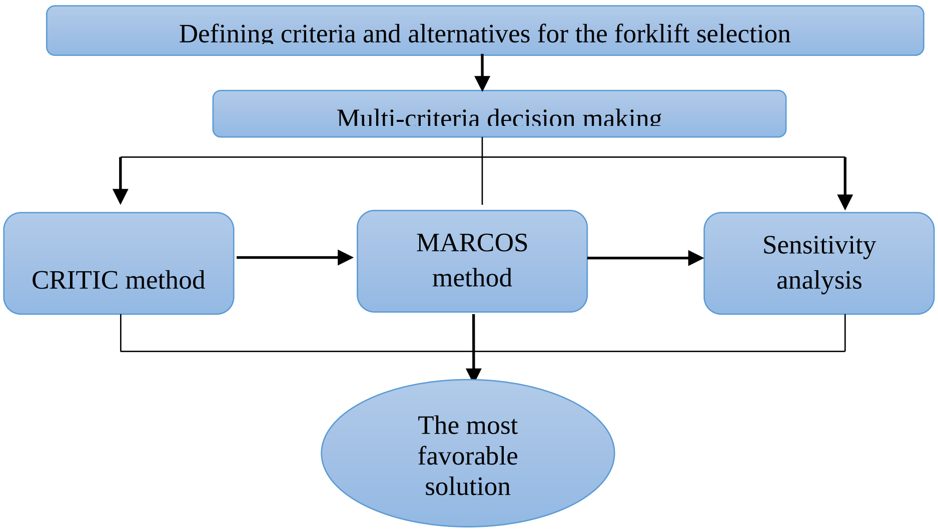

Figure 1. Research methodology

2.1 CRITIC method

The CRITIC method, Diakoulaki et al. (1995), consists of the following steps.

Step 1. The initial matrix (*X*) is expressed as follows:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} i = 1,2,\dots,m;\ j = 1,2,\dots,n \tag{1}$$

Where (*i=1,2, ...,m i j= 1,2,...,*n).

Step 2. Normalization of the initial matrix is performed as follows:

a) For benefit criteria

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad if\ \ j \in B \to \max \tag{2}$$

b) For cost criteria

$$r_{ij} = \frac{x_{ij} - \max_i x_{ij}}{\min_i x_{ij} - \max_i x_{ij}} \quad if\ \ j \in C \to \min \tag{3}$$

Step 3. In the continuation of the method, it is necessary to construct a symmetric matrix with elements (m_{ij}) that represent the coefficients of linear correlation of vectors.

Step 4. Determining the objective weight of criteria by the CRITIC method also requires estimating both the standard deviation of the criterion and its correlation with other criteria. Thus, (w_j) is obtained using the following equation:

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{4}$$

Where C_j is the amount of information contained in the criterion and is determined as follows:

$$C_j = \sigma \sum_{j'=1}^{n} 1 - r_{ij} \tag{5}$$

Where σ is the standard deviation of the *j*-th criterion and the correlation coefficient between the two criteria.

2.2 MARCOS method

The MARCOS method is conducted through the following steps, Stević et al. (2020), Ulutas et al. (2020). Step 1: Forming an initial decision matrix.

Step 2: Forming an extended initial matrix. In this step, the initial matrix is expanded by defining the ideal (*AI*) and anti-ideal (*AAI*) solution.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \ldots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \ldots & x_{aan} \\ x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{22} & \ldots & x_{mn} \\ x_{ai1} & x_{ai2} & \ldots & x_{ain} \end{bmatrix} \end{array} \tag{6}$$

The anti-ideal solution (*AAI*) represents the worst alternative, while the ideal solution (AI) represents the alternative with the best characteristic.

$$AAI = \min_i x_{ij} \quad if \;\; j \in B \quad and \quad \max_i x_{ij} \quad if \;\; j \in C \tag{7}$$

$$AI = \max_i x_{ij} \quad if \;\; j \in B \quad and \quad \min_i x_{ij} \quad if \;\; j \in C \tag{8}$$

Where *B* represents a benefit group of criteria, while C represents a non-benefit group of criteria.

Step 3: Normalization of the extended initial matrix (*X*).

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if \;\; j \in C \tag{9}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if \;\; j \in B \tag{10}$$

Step 4: Determining the weighted matrix $V=[v_{ij}]_{mxn}$.

$$v_{ij} = n_{ij} \times w_j \tag{11}$$

Step 5: Calculation of the degree of utility of the alternative K_i.

$$K_i^- = \frac{S_i}{S_{aai}} \tag{12}$$

$$K_i^+ = \frac{S_i}{S_{ai}} \tag{13}$$

Where S_i ($i=1,2,\ldots,m$) represents the sum of the elements of the weighted matrix:

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{14}$$

Step 6: Determining the utility function of the alternative $f(K_i)$.

$$f\left(K_i\right) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}}; \tag{15}$$

Where $f(K_i^-)$ represents the utility function in relation to the anti-ideal solution, while $f(K_i^+)$ represents the utility function in relation to the ideal solution. The utility functions in relation to the ideal and anti-ideal solution are determined by applying:

$$f\left(K_i^-\right)=\frac{K_i^+}{K_i^+ + K_i^-} \tag{16}$$

$$f\left(K_i^+\right)=\frac{K_i^-}{K_i^+ + K_i^-} \tag{17}$$

Step 7: Ranking the alternative.

3. APPLICATION OF INTEGRATED CRITIC-MARCOS MODEL FOR FORKLIFT SELECTION

In large companies such as Natron-Hayat, it is necessary to pay special attention when it comes to the selection and purchase of forklifts. Natron-Hayat is one of the largest exporters in the country. Given that this is a decentralized and complex warehousing system, it is necessary to constantly monitor activities and create models for further improvements. Taking into account that it is a large logistics company, the optimization of parameters in the warehousing system can bring superior results that represent the achievement of greater business success. Since in Natron-Hayat company, forklifts work in different types of warehouses, it is important to select a forklift that will meet all requirements.

Below are the criteria on the basis of which the ranking and selection of the most favorable forklift was performed. C1 – Purchase price, C2 – Load capacity, C3 – Lifting height, C4 – Lifting speed, C5 – Lowering speed, C6 – Driving speed, C7 – Battery capacity, C8 – Noise level, C9 – Spare parts supply. The criterion of spare parts supply means that when servicing and repairing a forklift, the parts are as accessible and easily accessible as possible. In this case, the distance of the companies representing agents for these types of forklifts was taken into account. Representatives are: Hyster forklifts represented by Misir BMJ-Široki Brijeg (distance from Maglaj is 256 km), Linde forklifts represented by Vanadium Company-Laktaši (distance from Maglaj is 117 km), Still forklifts represented by Benprom-Gračanica (distance from Maglaj is 44 km), Toyota forklifts represented by Ednil - Sarajevo (distance from Maglaj is 123 km).

3.1 Determining the criterion weights using the CRITIC method

Step 1. The initial matrix (X) is shown in Table 1.

Table 1. Initial matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	11450	2041	4557	0.3	0.57	9.9	36	65	256
A2	15250	1600	4300	0.4	0.6	15.8	48	64	117
A3	10900	1600	3230	0.3	0.54	12	24	63.9	44
A4	14500	2500	3340	0.46	0.56	19	80	68.8	123
MAX	15250	2500	4557	0.46	0.6	19.0	80	68.8	256
MIN	10900	1600	3230	0.3	0.54	9.9	24	63.9	44

Applying the other steps of the CRITIC method, the final values of the criteria presented in Table 3 are obtained.

Table 3. Weights of criteria

C1	C2	C3	C4	C5	C6	C7	C8	C9
0.159	0.110	0.127	0.096	0.089	0.089	0.086	0.137	0.106
1	**4**	**3**	**6**	**7**	**8**	**9**	**2**	**5**

3.2 Evaluation and selection of forklifts using the MARCOS method

Step 1: Forming an initial decision matrix, presented in Table 1.

Step 2: Forming an extended initial matrix. In this step, the initial matrix is expanded by defining the ideal (*AI*) and anti-ideal (*AAI*) solution, using Eqs. (6), (7) and (8).

Step 3: Normalization of the extended initial matrix (*X*). The elements of the normalized matrix are obtained by applying Eqs. (9) and (10), and shown in Table 4.

$$n_{11} = \frac{x_{ai}}{x_{ij}} = \frac{10900}{15250} = 0.715, \qquad n_{12} = \frac{x_{ij}}{x_{ai}} = \frac{1600}{2500} = 0.640$$

Table 4. Normalized initial matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
AAI	0.715	0.640	0.709	0.652	0.900	0.521	0.300	0.929	0.172
A1	0.952	0.816	1.000	0.652	0.950	0.521	0.450	0.983	0.172
A2	0.715	0.640	0.944	0.870	1.000	0.832	0.600	0.998	0.376
A3	1.000	0.640	0.709	0.652	0.900	0.632	0.300	1.000	1.000
A4	0.752	1.000	0.733	1.000	0.933	1.000	1.000	0.929	0.358
AI	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Step 4: Determining the weighted matrix using Eq. (11).

Step 5: Calculation of the utility degree of the alternative using Eqs. (12) and (13)

$$K_i^- = \frac{S_i}{S_{aai}} = \frac{0.754}{0.635} = 1.187, \qquad K_i^+ = \frac{S_i}{S_{ai}} = \frac{0.754}{1} = 0.754$$

Where S_i represents the sum of the elements of the weighted matrix, Eq. (14): $S_{aai} = 0.114 + 0.070 + 0.090 + 0.063 + 0.080 + 0.046 + 0.026 + 0.127 + 0.018 = 0.635$

Step 6: Determining the utility function of the alternative *f(Ki)*. The utility function of alternatives is defined by applying Eq. (15). The utility functions in relation to the ideal and anti-ideal solution are determined by applying Eqs. (16) and (17):

$$f\left(K_1^-\right) = \frac{K_i^+}{K_i^+ + K_i^-} = \frac{0.754}{0.754 + 1.187} = 0.388, \quad f\left(K_1^+\right) = \frac{K_i^-}{K_i^+ + K_i^-} = \frac{1.187}{0.754 + 1.187} = 0.612$$

Step 7: Ranking the alternatives. The ranking of the alternatives is based on the final values of the utility functions, Table 5.

Table 5. Results obtained using the MARCOS method

	Si	Ki-	Ki+	fK-	fK+	Ki	Rank
A1	0.754	1.187	0.754	0.388	0.612	0.605	4
A2	0.779	1.227	0.779	0.388	0.612	0.625	3
A3	0.788	1.241	0.788	0.388	0.612	0.632	2
A4	0.842	1.327	0.842	0.388	0.612	0.676	1

4. SENSITIVITY ANALYSIS AND COMPARATIVE ANALYSIS

We know that there are different methods of MCDM, and the results often change depending on the change in the significance of the criteria as well as the selection of the MCDM method. For that reason, it is necessary to perform a sensitivity analysis, i.e. to compare the results when the weights of criteria change and to compare the results of different methods. Sensitivity analysis is performed for greater security during implementation in the real sector.

4.1 Analysis of the sensitivity of the results to changes in the significance of the criteria

In this part of the sensitivity analysis, the impact of the change of the three most important criteria, C_1, C_8 and C_3 was analyzed. By applying Eq. (18), Erceg et al. (2019), a total of 18 scenarios were formed.

$$W_{n\beta} = \left(1 - W_{n\alpha}\right) \frac{W_\beta}{\left(1 - W_n\right)} \tag{18}$$

In scenarios S_1-S_6, it was changed the most significant criterion C_1, criterion C_8 in scenarios S_7-S_{12}, criterion C_3 in scenarios S_{13}-S_{18}.

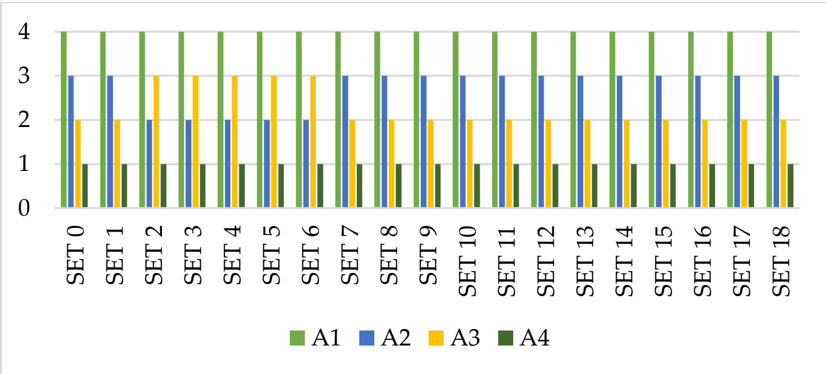

Figure 6. Results of sensitivity analysis at new criterion values

Based on 18 sets that represent the new criteria, we see that there has been no significant change. Although the criteria have been changed, we come to the conclusion that the first alternative is the worst solution, while the fourth alternative is the best solution. The only change is that the second and third alternative alternate depending on the significance of the criteria.

4.2 Comparative analysis

We tested the rank of alternatives by comparing the results obtained using the MARCOS method with the results of ARAS, Zavadskas and Turskis (2010), MABAC, (Ibrahimović et al. 2019), SAW, (Kishore et al. 2020), WASPAS, (Zavadskas et al. 2012) and EDAS method, (Keshavarz Ghorabaee et al. 2015). Based on the results from Table 6, we can conclude that the fourth alternative, i.e. the TOYOTA 8FBMT 25 forklift retains the first position and is the best solution in four of the five applied methods. Also, the first alternative is the worst solution in these methods. The second and third alternative also retain their rank in four of the five methods.

Table 6. Ranking of alternatives for all applied methods

	MARCOS	ARAS	MABAC	SAW	WASPAS	EDAS
A1	4	4	3	4	4	4
A2	3	3	1	3	3	3
A3	2	2	4	2	2	2
A4	1	1	2	1	1	1

Based on all the above, we see that there is a different rank of alternative only with the MABAC method.

5. CONCLUSION

After a detailed analysis of Natron-Hayat's requirements and needs for an additional forklift, four were analyzed through nine criteria belonging to different groups. To analyze the collected data, it was used an integrated CRITIC-MARCOS model. The CRITIC method is an objective MCDM method and it was applied to calculate weight coefficients which were then used in the MARCOS method to weight the initial values. By analyzing the collected data using the MARCOS method, it was performed the ranking of alternatives, according to which alternative A4 is the most favorable alternative, while alternative A1 is the worst alternative. In the sensitivity analysis section, the same data were analyzed using five other MCDM methods. When comparing the final results, the rank of alternatives did not change significantly; alternative A4 remained at the top of the rank in four of the five methods used in the paper, which means that the TOYOTA 8FBMT 25 forklift is the most suitable solution out of the set of alternatives. By applying the previously described integrated model, significant results have been achieved in terms of defining future strategies referring to warehousing system operations. The continuation of this research can be defined in several directions. One of them is the application of this or a similar model to other subsystems in the company in order to achieve greater synergy with the overall logistics system. The other direction is the re-application of the model over time, considering a set of data in uncertain situations, which have become commonplace.

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WHAT ARE MANAGERS THINKING ABOUT WMS?

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Abstract: *The aim of this study is the identification of the main benefits and costs of installing a Warehouse Management System (WMS) in a company. Logistics managers of 7 big 3PL's in Greece using WMS were interviewed. The survey was conducted from December 2021 to March 2022. According to the responses, businesses have been able to minimize errors by saving time. Moreover, WMS along with Radio Frequency (RF) gives its user the essential information about the operation he has to perform with precision and speed. Some suppliers have access to their customers' systems and thus anticipate the demand themselves, avoiding not only shortages but also the accumulation of goods in the company's warehouses. Customers are more satisfied as they receive their orders at the right time, quality and quantity. Costs in purchasing, maintaining and supporting software and equipment increased while labor cost, error cost and destruction of goods decreased. The current study confirms the literature and highlights specific pros and costs that might lead to new WMS installations.*

Keywords*: Warehouse Management Systems, Warehousing, Cost, Benefits, Thematic Analysis.*

1. INTRODUCTION

The development of e-commerce brought great changes in product distribution. Logistics services providers in order to adapt to the new environment expand their warehouses and create more delivery points for their products to the last mile customer. They try to achieve faster deliveries to cover the whole territory. They also invest in IT applications to minimize delivery errors. Moreover, they try to be flexible in high mobility periods such as Black Friday, Christmas, discounts, etc. This can only be achieved by using a Warehouse Management System (WMS).

As Folinas and Fotiadis (2017) defined "*WMS helps companies to automate, simplify, optimize and redesign the related business processes and also helps the decision-makers to make better decisions regarding warehousing and inventory control*". WMS deals with all processes that take place in one or more warehouses or branches. Assists in the organization, supervision and execution of daily procedures in the warehouse. It is

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therefore clear that the warehouse management information system needs to be studied more thoroughly and scientifically and also the benefits and costs arising from its installation in a business.

The aim of this study is the identification of the main benefits and costs of installing a WMS in a company. Logistics managers of 7 big Third Party Logistics Providers (3PL's) in Greece using WMS were interviewed. The survey was conducted from December 2021 to March 2022. According to the responses, businesses have been able to minimize errors by saving time.

The following the paper is organized as follows. In the next section a synoptic literature review is given that defines the WMS and identifies their expected benefits.

2. LITERATURE REVIEW

A Warehouse Management System (WMS), is a software application that supports everyday tasks that take place in a warehouse. WMS allows centralized management of work in a warehouse, from tracking the amount of inventory to placing it in appropriate locations within the storage area. It is developed to speed up loading/unloading time, improve the validity of the stock list, optimize the management of warehouse space and enhance its productivity. Typically, a WMS performs a variety of warehouse operations essential to its day-to-day operation (Richards, 2014; Tompkins et al. 2010).

WMS application is an informative system whose role is to manage inventories moving within a warehouse or more. It works in real-time and guarantees fast and accurate information. Operates with the help of barcode and radio frequency (RF) detectors and manages the operations of a warehouse or distribution center. It consists of a database server, an application server, and a client (Entersoft, Installation & architecture, configuration and add-on development tools, 2010). The main modules of a WMS according to Entersoft are Receipts, Shipments, Returns, Production, Stock, Inventory, Overview, Items, Layout and Resources (Entersoft, Entersoft WMS-UserGuideEN, 2020).

Businesses today aim to make better decisions so that they can have better financial results and improve their relationships with their suppliers and customers (Laudon & Laudon, 2009). Also, orders tend to become smaller and more frequent and customers have higher demands. Finally, businesses aim for economies of scale and maximize storage capacity (Folinas and Fotiadis, 2017).

The advantages of installing a WMS system in a company are: systems integration (Software Market, 2022), improved employee productivity and customer satisfaction (Hitchings, 2022), automated and upgraded warehouse processes, and data immediacy (Treadaway, 2020), and remote access. In addition, cost reduction, optimal layout, reduced time, shortage management, better control of all production phases, and faster inventory procedures are achieved.

On the other hand, there are some drawbacks such as:

- The constantly evolving technology: Because each system is compatible with specific hardware & software, new versions being developed create barriers and additional costs,
- Staff: Such a system needs specially trained staff to operate it, which is quite difficult as the system is constantly improving and becoming more complex, and

- Time: Installing an application and upgrading it takes time for user training and debugging.

2. RESEARCH METHODOLOGY

The research method used in this research is in-depth interviews. The survey was conducted from 14 February 2022 to 1 March 2022 in Thessaloniki. The sample was Logistics managers of companies based in Northern Greece. Due to anonymity, we name the companies: LM1, LM2 to LM7.
The business domains of the targeted companies are presented below:

- LM1: super market,
- LM2: beverage industry,
- LM3: flour mill industry,
- LM4: 3pl,
- LM5: pharmaceutical compounding development industry,
- LM6: thermal insulating industry and
- LM7: sporting goods retailer.

Each manager answered a questionnaire with open questions that, first, aims to sketch the profile of the companies and their warehouse systems. According to the responses, the examined companies have organized warehouses that act as distribution centers for their customers/points of sales. The number of employees in the warehouses of the above companies ranges from 5 to 1000 people. The installation date of WMS ranges from 2000 to 2013. The total size of their warehouses is from 2,000sqm to 125,000sqm.

Before installing WMS, many used ERP systems while the rest either manuscript or custom applications, or had WMS since the founding of the company. The number of physical warehouses ranged from 1 to 5 with most having answered 5. The storage systems used by companies in their warehouses are shown in the following diagram.

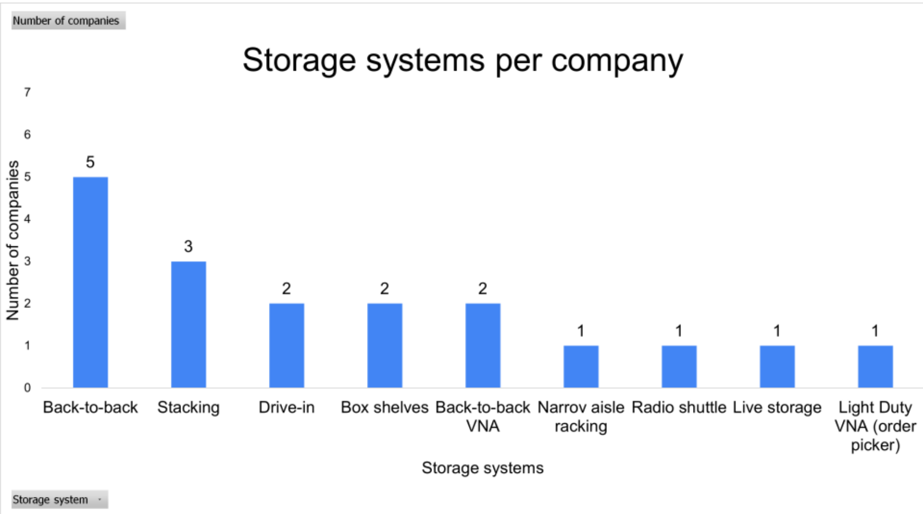

Figure 1: Storage systems

Then, some questions aim to answer the research questions, and specifically:

1. Why did you invest in WMS?

2. After the installation of WMS, was there a decrease or increase in the company's storage needs?
3. In which basic functions of your warehouse was a reduction in human error observed?
4. How was the warehouse clerk assisted in finding the exact location of the stocks and their current balance? How was this achieved?
5. How is now your cooperation with your suppliers in terms of the exchange of information concerning stocks?
6. The execution time of the order consists of three sub-times: the processing time of the order, the collection time of the products and the loading and delivery of the products to the customer. How were these times affected by WMS?
7. How are stock shortages now addressed and how is it possible to avoid the accumulation of large quantities of warehouse items?
8. How has your customers' experiential experience been affected?
9. What sub-operating costs of the warehouse have been affected?
10. How has the productivity of the workers in the warehouse been affected?
11. To what extent the process of tracking product expiration dates help economies of scale?

3. RESEARCH FINDINGS

In this section, the responses to the questions that were provided in the methodology section are presented as quotes.

3.1 Why did you invest in WMS?

LM2: The increase in project volume and the need for tracking across the supply chain spectrum "forced" the upgrade to a WMS system.

LM3: Season and evolution require WMS.

LM4: In the context of the reorganization of the company, it was strategically decided to purchase a WMS to have the necessary tools and to support the functions that a reliable 3PL company must provide, as well as to have the conditions for quick and complete adaptation to their customers' needs.

LM5: The reasons for investing in a WMS system are the following: Better order management, reduced order shipping time, reduced errors, better inventory management and finally reduced time in other warehousing processes.

LM6: The main reasons for investing in WMS were the optimization of spatial planning, employee performance and physical inventory.

LM7: WMS system is essential for warehouse productivity which with traditional picking lists can be up to 5 times higher.

3.2 After the installation of WMS, was there a decrease or increase in the company's storage needs?

LM2: Initially, there was a better settlement of the existing stock. Later, the growing volume of the project forced the increase of warehouses by 60%

LM4: There was a rapid increase, 60% since 2013, in both the number of customers and the required space as it became possible to manage, through the WMS, customers with greater complexity.

LM5: Neither was observed. The space was sufficient during the first years of operation of the warehouse.

LM6: WMS installation did not affect storage needs. The increase in storage space is mainly attributed to an increase inactivity.

LM7: In general WMS reduces space requirements.

3.3 In which basic functions of your warehouse was a reduction in human error observed?

LM1: In all functions, the guidance through specialized software leads to error reduction.

LM2: In all functions, there was a reduction in errors and time-saving.

LM3: Picking and movings.

LM4: On the one hand All the basic operations (receipts, picking) became faster and on the other hand the errors were reduced and mainly they were detected faster thanks to the immediacy of the information provided by the WMS.

LM5: There has been a reduction in human error in order management, product shipping, inventory management and product receipt.

LM6: Incorrect loading of items and quantities.

3.4 How was the warehouse clerk assisted in finding the exact location of the stocks and their current balance? How was this achieved?

LM1: There is a better perspective on the stock layout and higher access speed. The general way to achieve this is the normal recording of all physical movements with systemic procedures in real-time.

LM2: Due to the multi-storage space, the storekeeper does not "look" for the batches. He knows where they are through the system and saves time. Also, the First-Expired-First-Out (FEFO) service system that the company has set in sending the products helps a lot the employee.

LM3: The system with multiple search modes from its menu can lead the warehouse employee to the right position.

LM4: Helped a lot through standard search forms that a modern WMS has.

LM5: By using WMS he knows exactly at any time where each product is located as well as the exact stock. The stricter the procedures defined, the more accurate the results.

LM6: Spatially we divided the warehouse into, 2,000 warehouse spaces with an easily identifiable number. It is possible to search inventory per location or collectively from a portable RF scanner. When collecting inventory for a sales order, the WMS displays in the RF scanner exactly the quantity of the item at a specific location. During the inventory, it is possible to continue the work due to the many separate locations.

LM7: WMS systems drive the picker to the product position. At picking, he scans the position and the product and the WMS removes it from the systems.

3.5 How is now your cooperation with your suppliers in terms of the exchange of information concerning stocks?

LM1: Some suppliers self-manage their stocks in our warehouses through Vendor Managed Inventory (VMI) and common monitoring goals regarding inventory and customer service.

LM2: The information is immediate and complete as I know what I have and when it was produced and will expire.

LM3: Much better in terms of traceability and error logging.

LM4: As we are not a commercial company, VMI does not apply. But sending the stock daily and in real-time to the customers helped a lot.

LM5: We have an accurate picture of each stock so we can make our orders to suppliers easier and even give a forecast for our future needs.

LM6: It has not changed. We still rely on ERP. Of course, the uncertainty regarding the accuracy of quantities has been greatly reduced.

LM7: The accuracy of the stocks is one of the most important points, especially now that the e-shop is developing. WMS systems offer this accuracy in stocks.

3.6 The execution time of the order consists of three sub-times: the processing time of the order, the collection time of the products and the loading and delivery of the products to the customer. How were these times affected by WMS?

LM1: Reduced due to standardized and fast processing and the direct distribution of information between production phases.

LM2: Collection time significantly reduced by about 40%.

LM3: Gradually not affected at all. Only initially did we have delays until users get used to it.

LM4: There was a great improvement mainly in the processing of the order by the customer service as the receipt of orders was reduced to a minimum through import files, registration errors are avoided and stock control procedures are done directly through the WMS. Clearly, the collection of orders via RF terminals has improved compared to the paper picking list but mainly the quality of stock information has improved.

LM5: The collection time has been reduced a lot as with the use of Personal Data Assistants (PDA) scanner the application leads you to exactly the place you need to collect the product. Also, having mapped the warehouse in the appropriate way we now can follow the shortest route to collect our order. Respectively the lead time has been reduced as everything is done exclusively with the use of a scanner.

LM6: Office processing time increased. The remaining times were reduced.

LM7: Order processing is also done by WMS but the main benefits come from the fast pick n pack. At the moment we use 400 lines with 600 pcs per hour per picker.

3.7 How are stock shortages now addressed and how is it possible to avoid the accumulation of large quantities of warehouse items?

LM1: Inventory adequacy ratios with quantitative and qualitative characteristics are monitored. Good visibility in stocks allows you to get an immediate picture of the needs and automate checks or refills.

LM2: Through parameters provided by the WMS one can configure the limits within which he wants his warehouse to operate.

LM3: By forecasting through the recorded consumables.

LM4: This does not apply to our type of company. However, we provide better and more immediate stock information.

LM5: We depend on our ERP system to address these issues.

LM6: It didn't change. We still rely on ERP. Of course, the uncertainty regarding the accuracy of quantities has been greatly reduced.

LM7: With gradual receipts and with the planning of imports.

3.8 How has your customers' experiential experience been affected?

LM1: Better service at the service point, quantitatively and qualitatively.

LM2: Because many customers set rules for accepting products regarding expiration dates and old batches, these kinds of failures have been minimized and the customer now gets what he has asked for as he has requested.

LM3: Positive. Organization and good image.

LM4: Reducing errors, stock information and orders, available KPI's enhanced our customers' loyalty with mutual financial benefits.

LM5: Our customers are more satisfied as the service time is shorter and the quality of our services is higher (fewer mistakes).

LM6: It has not changed. We still rely on ERP. Of course, loading errors in terms of items and quantities have been reduced.

LM7: It has been affected quite positively.

3.9 What sub-operating costs of the warehouse have been affected? (Decrease or increase)

LM1: Reduction of labor costs, reduction of goods disasters, smaller stocks, an increase of costs for purchase, maintenance and development of software, increased costs in technological equipment and its renewal.

LM2: 30% reduction in inventory, 40% reduction in safety stock, 25% reduction in warehouse costs, and increase in IT costs.

LM3: Increased maintenance costs of WMS and RF. The cost of a mistake was reduced.

LM4: The main cost in a 3PL warehouse is labor cost. By using WMS employees produce more work at the same time. Employee costs as a percentage of income have been reduced.

LM6: No quantitative comparison can be made because the size of activity is completely different before and after the implementation of WMS.

LM7: Labor costs have fallen due to increased productivity.

3.10 How has the productivity of the workers in the warehouse been affected?

LM1: Productivity is more directly and transparently measurable. In some processes, it is increased and in others, it is decreased due to the imposition of a stricter framework. The previews and after situations are not comparable as the whole production system changes at the same time in goals, duration, and quality.

LM2: Increased by 40%.

LM3: Productivity remained stable despite the additional needs of the WMS.

LM4: Simplification of procedures and promptness of information has rapidly reduced the execution time of any task. The operation of WMS in combination with the use of RF and Vision Picking systems ensures the correct and fast execution of orders.

LM5: Significantly increased, shorter response time and fewer errors.

LM6: Increased.

LM7: Increased over 30%.

3.11 To what extent the process of tracking product expiration dates help economies of scale?

LM1: Less returns and product damage as well as quality stock analysis.

LM4: As a 3PL provider tracking expiration dates is just a stock feature. The customer has the economic advantage since the goods to be destroyed and/or the returns to the factory have been reduced to a minimum.

4. CONCLUSIONS AND DISCUSSIONS

The main reasons for investing in a WMS are: time saving, reduction of errors and better control-tracking of goods. All these increase the productivity of the employee as well as the productivity of the entire warehouse and thus the company achieves economies of scale while increasing its activity. Warehouse needs were not affected by the WMS as it was the increase in project volume and not the WMS that led them to increase storage.

Businesses with a WMS succeed in reducing errors in almost all operations with an emphasis on the picking of goods. The employee helped himself the most in finding the position and the current balance. The WMS in combination with the RF scanner through the standard forms, that provide, give to the employee with precision and speed the necessary information for the operation that he has to perform. The processing, picking and loading times of the goods were reduced to a greater extent due to the speed and flexibility provided by the system.

It seemed that in some companies their suppliers have access to their customer systems and thus anticipate demand themselves, avoiding not only shortages but also the accumulation of goods in the company's warehouses. Deficiencies are also addressed through the feedback limits, re-ordering that they set in the system. Customers themselves are more satisfied as they receive their products exactly as requested, at the right time, quality and quantity.

Another important factor is cost. Research has shown that the cost of purchasing, maintaining and supporting its software and equipment has increased. On the other hand, labor costs, error costs and destruction of goods decreased due to increased productivity and reduced errors.

In this study a number of limitations exist. First, the small number of respondents. However, the examined companies are leaders in the corresponding sectors. Another limitation is the geographical area (North Greece), although in this area there is a big number of companies that fulfil not only Northern Greece but Balkan and Central European countries/markets.

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PART VII STUDENT'S SESSION

IMPLEMENTATION OF NEW INDUSTRY 4.0 IN SUPPLY CHAIN MANAGEMENT

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Abstract: *Industry 4.0's new digital technologies are changing business operations and supply chain performance. Companies are using modern technologies to transform their supply chains from basic operational hubs to the core of business innovation as a result of globalization, increased product complexity, and rising customer demand. In the supply chain, Industry 4.0 technologies and trends help meet client needs more efficiently. To optimize their global logistics, leading supply chains innovate and employ more technological solutions that increase visibility, data quality, and carrier connections. Although some companies are still hesitant to risk their supply networks, the paper examines key Industry 4.0 technologies that have provided many advances and benefits. Future supply chain trends are also discussed, as well as the directions in which they will evolve.*

Keywords: *Supply Chain, New Technologies, Future Trends, Industry 4.0.*

1. INTRODUCTION

The recent pandemic in 2020 affected every part of the supply chain (SC), from the procurement of raw materials to the end customer. It tests the commercial, operational, financial, and organizational resilience of most companies around the world. COVID-19 highlighted the risks and shortcomings of SC resilience. As the new geopolitical crisis between Russia and Ukraine began in February 2022, it caused an energy crisis and continued to affect the global SC. The main disturbances it causes are production delays, a limited number of third parties, labor shortages, and rising commodity prices (Syed & Zhang, 2021; Hosse, 2022).

The SC environment generates higher business challenges than before. The impact of the COVID-19 pandemic is inevitable. A series of closures and restrictions, including transport bottlenecks, varied in time and severity from country to country. The COVID-19 pandemic was not just a short-term crisis. It has long-standing implications for how employees and SC function. Companies need to build long-term resilience in their value SC to manage future challenges (Syed & Zhang, 2021; Hosse, 2022).

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The economic and business environments have become more challenging. In the UK and the rest of Europe, pressures on the SC have been caused by Brexit as a result of increased bureaucracy and cross-border checks. In a broader sense, companies continue to face a range of international business challenges, ranging from fluctuating courses to building global management teams. This is important as the business has become increasingly international—often global—in recent years due to the reduction of traditional barriers to the cross-border movement of products, services, capital, people, and information (Syed & Zhang, 2021; Evans, 2021). The impact of logistics and SC activities on the environment is beginning to be increasingly understood. If countries around the world want to meet their emissions targets and obligations, they must develop more sustainable SC practices. Glasgow COP26 (UN Framework Convention on Climate Change to Reduce Carbon Emissions to Zero) had a strong focus on transport, including freight and logistics. Normal business is no longer an option if a sustainable future is achieved (Fornasiero et al., 2021).

Companies need to react quickly and confidently to design and implement a short-term tactical plan and a long-term strategic plan that will mitigate risks and protect the functioning of global SC. A wave of new trends and challenges in the SC is generating new prospects driven by new technologies to ensure customer expectations for high-quality delivery of reliable products at an affordable price. The vision of the future SC is based on digitalization and the implementation of Industry 4.0 (Fornasiero et al., 2021; Lowe, 2022; Pierce, 2020). Technologies such as IoT, Blockchain, Cloud Computing, 5G, and Digital Twin Supply Chains would increase and develop efficiency, bringing faster, more flexible, more detailed, and more accurate SC.

2. TECHNOLOGIES IN SUPPLY CHAIN MANAGEMENT

Digitization is taking over the entire logistics and SC. It will intensify in the coming years, and the COVID-19 pandemic has only accelerated it. The SC continues to evolve and change rapidly, keeping pace with the technological advances of the modern era. Companies need to be up to date with new technologies that can help them improve the efficiency of their business. With the help of technology, the manager can optimize the SC to secure undisturbed functioning and prevent unwanted events. IoT, artificial intelligence, 5G networks, blockchain, cloud computing, and digital twins are just some of the technologies that contribute a lot to supply chain management (SCM). IoT and Blockchain itself are predicted to speed up the SCM and reduce the occurrence of adverse events (Syed & Zhang, 2021).

2.1 IoT – Internet of Things

The first SCM technology expected to grow is the IoT. The Internet of Things is a network of physical objects that are powered by sensors and software and connected to the Internet. The main drivers of IoT growth are the availability of cheap and reliable sensors, the penetration of the Internet, a huge increase in storage capacity, data processing, and the emergence of artificial intelligence. IoT plays a significant role in the SC, especially when it comes to logistics, with increasingly diverse applications and will continue to grow. In just a few years, 50% (Evans, 2021) of large companies could use IoT and other advanced technologies to support SC operations. The future of IoT is projected to lead to a 15% increase in productivity in the SC (Lowe, 2022).

In addition to providing greater oversight of operations and transportation, it is believed that IoT can be used to improve warehouse management, fleet monitoring, inventory control, and technological and mechanical maintenance. IoT technology could also be used to create completely smart warehouses and fleets, increasing the efficiency and accuracy of the SC. Depending on which IoT devices are used, they can be combined with other technologies to achieve even greater benefits. A high level of integration will be essential as the SC raises the level of digitization. The SC has historically been a black box for businesses, with customers not knowing where and in what condition their goods are. Manufacturers are wasting a lot of time, money, and supplies due to unforeseen freight movements. India alone spends about $160 billion (Evans, 2021; Lowe, 2022; Pierce, 2020; Evans, 2021) on-road logistics, twice as much as countries with efficient transport infrastructure. Many companies are already turning to artificial intelligence to optimize their SC.

2.2 Artificial intelligence and 5G

Artificial intelligence will play a key role in improving SC efficiency. The technology can be used to automate procedures using an algorithm based on data from previous processes. Automation makes SC more efficient, eliminating human error. The use of artificial intelligence is on the rise in many SC. In a world where speed and precision are key to success, artificial intelligence is a great way to speed up the SC and compete. The increase in artificial intelligence is predicted to address many of the inefficiencies that are still present in today's SC. Artificial intelligence can design business models by changing the way we look at future SCM trends. It can also analyze patterns of today's processes (e.g. in manufacturing) and predict possible outcomes of future scenarios. The 5G networks that have appeared on the global stage are becoming very attractive, both because of the speed and the density of the devices. As IoT devices have flooded the market, networks that can handle a huge number of devices are needed. The difference between 4G and 5G networks is staggering, as 4G networks can only manage about 10,000 devices per square mile, compared to 5G, which can support almost 100 times the amount (Lowe, 2022; Pierce, 2020). 5G is expected to not only improve the quality of life but also optimize vital parts of the SC, from supply to distribution and warehousing management.

2.3 Blockchain

SC visibility is a major source of concern for most companies, and for this reason, more and more of them want to integrate blockchain technology into their chains. It can help improve the transparency of the entire SC, reduce interference, and improve communication with customers. Through blockchain, all chain components can be integrated into a single platform. Carriers, delivery lines, shippers, and logistics service providers can use the same platform to inform companies and customers about the journey of their products. Blockchain also provides unparalleled information protection. Technology has the potential to positively impact SC processes in three key areas: providing accurate, up-to-date information at all times; ensuring the visibility of data and information to all stakeholders; and ensuring the security of all information contained in the blockchain. As time goes on, technology evolves, and there is no doubt that those who get used to this technology will be a big step ahead of the competition (Lowe, 2022; Evans, 2021).

2.4 Cloud Computing

Cloud-based software solutions represent the future of SCM. All data is stored in the cloud, information can be obtained at any time, and there is great reliability and security. Cloud computing now provides various degrees of capability and security while lowering costs and addressing issues associated with traditional software adaptations. The cloud market is projected to grow in 2022 and beyond (Evans, 2021). Recent reports show that the cloud-based SCM market is growing to nearly $8.6 billion by 2025 (Lowe, 2022). Companies need technology platforms that will enable product visualization at every stage of their life cycle, in real-time, from raw materials through delivery to the end customer. Management must be able to make quick decisions on redirecting deliveries, locating containers, and cooperating with suppliers to meet customer demand. The real power of cloud computing lies in the way it changes the computing economy. By packaging and delivering computer services as a utility, consumers of those services have the benefits of ubiquitous access to computing infrastructure, along with the economic benefits of scale and the flexibility to pair service payments with the value they deliver to an organization. In today's highly competitive global environment, companies need SC that is agile, smart, and adaptable. Customers, suppliers, and partners are demanding. They want information immediately and demand that the right products arrive at the right location at the right time. This can best be achieved by using cloud computing. Instead of a manually operated SC, solutions are used that will transform the SC into an automated, dynamic SC that offers accessibility, control, and cooperation between all partners (Pierce, 2020).

2.5 Digital Supply Chain Twins

As social distancing becomes the norm, making decisions based on real-time SC data using manual methods is becoming less attractive. On the other hand, real-time data is necessary to avoid all interference and problems. Digital SC twins meet this need by creating an entire SC and their processes in an easily accessible, digital environment. Real-time information collected from IoT devices can give a crystal clear picture of everything from customer orders to individual items moving through the SC. Digital twins can point out production delays and their possible consequences, give notifications of equipment failures or things that need to be repaired, etc. (Lowe, 2022).

A digital SC twin is a detailed simulation model of the real SC that uses real-time data, based on which analysts can understand the behavior of the SC, predict possible situations, and create an action plan. Data is collected from sources such as IoT devices (e.g. sensors); logistics and transport databases; operational databases; vendor information; and user experiences. With the help of digital twin technology, overall SC processes can be optimized by tracking certain risks, identifying bottlenecks, transportation planning, optimizing inventory, and predicting the performance of packaging materials. Also, many challenges can be overcome; that is, data quality can be improved and the adoption of new technologies can be increased (Evans, 2021; Lowe, 2022).

3. FUTURE TRENDS IN SUPPLY CHAIN MANAGEMENT

Different industries and companies of different activities on a global level are constantly fighting against major disruptions that occur during the realization of SC. The goals of these industries and companies are to optimize the realization of SC themselves, reduce the risks involved, improve efficiency, and ultimately identify ways in which they could gain an advantage in the market compared to existing competition. To achieve these goals, it is essential to overcome today's intense and ubiquitous challenges. In addition to the mentioned challenges, it is necessary to apply digital technologies in the right way, rationally manage supply and inventory, and define priority and customer focus. Defining key trends will enable SC to proactively shape a successful and sustainable strategy. SC will continue to evolve exponentially, keeping pace with the technological advances of the modern age. For these reasons, the organization and implementation of SC must try to keep pace with all the global changes in the market (Syed & Zhang, 2021; Alice, 2022).

3.1 Shorter product life cycle

Reducing the lifespan of products affects the fact that companies make various innovations in the organization of their own business to be able to operate efficiently and profitably. When product life is shorter, customers will continue to demand as many new products as they can meet, while companies will have to deliver those new products within defined deadlines. For these reasons, SC needs to run faster and more efficiently (Alice, 2022). In addition, different products with different lifespans will require the existence of different SC, which further complicates the overall organization. Many companies use the same chain for all products, despite the differences in their lifespans. For that reason, they will have to develop a variety of strategies to maintain their profitability. Advanced tools and technologies can help track inventory and automate the ordering process. To this end, companies will simplify their return logistics processes to improve the handling of obsolete products (Filipović, 2022).

3.2 Flexibility of Supply Chains

SC adaptability can be defined as the ability to adjust the SC configuration to meet structural changes, various disruptions during implementation, as well as changes in customer behavior. Adaptive SCM provides insight into the dynamics, complexity, and uncertainty during implementation, further increasing stability and resilience in the event of disturbances and crises (Alice, 2022). The traditional way of SCM was linear within all components, i.e., all parts functioned together, thus achieving the appropriate price, quality, and speed of implementation. In such management, agility and flexibility are lacking in cases of various internal or external changes. Some of the advantages of this way of managing SC are (Slevin, 2022):

- Better adjustment and redesign of the supply network in response to external changes,
- Identification and response to changes in customer preferences and requirements,
- Transparency and visibility of supply chains from start to finish,
- Improving business innovation based on real-time feedback.

3.3 Sustainability of Supply Chains and Green Logistics

The sustainability of SC is defined as complementing traditional ways of SCM by adding environmental, social, and corporate aspects to the procurement of raw materials, production of finished products, and delivery to customers. In addition to environmental benefits, companies that use sustainability principles in their SC save money on storage, delivery, and expired products. By applying sustainability in SC, the benefits are reflected in three aspects: customers, profits, and the planet (Kluwer, 2021). Customers and SC entities are becoming increasingly concerned about environmental issues, which has an impact on the brands that promote and address sustainability concerns. Consumer knowledge and environmental concern are growing, influencing the SC to become less and less environmentally harmful. At the same time, there is a trend of green logistics, which is becoming more popular due to increasing CO2 emissions during transport. Green logistics is just one of many trends affecting storage in SC. Eco-warehouses have an advanced energy management system that uses meters to monitor energy consumption, heating, water, and gas in all facilities. Such systems help reduce excessive resource consumption. Electric and powered vehicles are increasingly used in supply chains, and such vehicles reduce the overall carbon footprint of the chain (Filipović, 2022; Alice, 2022).

3.4 Improving the predictability of Supply Chains

Predictability will become a competitive advantage as the SC breaks through barriers and obstacles and becomes more economical, secure, and faster. Most companies want to improve their resilience to the constant fluctuations that occur during the realization of SC, but this creates additional high costs. The need to adopt new technologies has enabled companies to be competitive in the market. Companies that have invested more in digitalization and the development of modern ways of doing business now have leading roles in the market. Innovation in ongoing operations and improvements can consume up to 90% of the IT budget (Hosse, 2022; Alice, 2022). One way to save money is to optimize existing IT resources. This achieves simplified, efficient operation of business processes and the ability to integrate with modern applications and technologies outside the company. However, the adoption of new technologies and their implementation brings with it certain risks that some companies are not ready for. An alternative to this is to maintain basic business applications because they are stable, meet certain needs, and perform essential tasks related to human resources and finances. This means that it is still possible to improve and develop basic applications, but there are deadlines for the end of full support for many existing software applications, which impose new technologies on companies. For some time to come, companies will be maintaining ERP (Enterprise Resource Planning) systems, reducing their current spending on IT, and shifting savings to invest in innovative technologies that will make the SC more resilient.

3.5 Using autonomous robots

Autonomous robots are designed to perform routine, repetitive tasks and operations that require complex programming, setup, and implementation. However, they are not intended for tasks that require a high degree of flexibility. As autonomous robots become more sophisticated, their advantages over humans during the realization of SC are increasing (Alice, 2022). In warehouses, autonomous robots will be used more and more to speed up demanding and hard work. Combined with the commonly used technologies, robots can significantly improve the productivity of SC (Filipović, 2022).

The increasing use of robots does not mean that they will completely replace humans. The technology is intended to increase human efficiency by speeding up the performance of simple tasks. If such tasks are performed by machines, people can dedicate themselves to more important tasks that have a direct effect on business growth and better communication with consumers (investors). The use of autonomous robots drives innovations in SC, which reduces direct and indirect operating costs and, in addition, increases revenue. Some of the benefits of using autonomous robots are (Fitzgerald, 2021):

- Reduction of risk, re-production, and error rates,
- Improving the safety of workers in high-risk environments,
- Performing simple tasks that will enable employees to focus on more complex tasks that cannot be automated and on their strategic work,
- Strengthened the corporate brand by following good practices and applying innovative technologies,
- Exponential learning by collecting and analyzing machine data.

4. CONCLUSION

In a relatively short time, the world has changed significantly. The SC is also changing, and chain management is no longer as simple as it used to be. However, technological advances provide more and more ways to optimize the SC. The SC's development, which largely depends on its environment, conditions the application of various digital technologies of the new era and the emergence of key trends for globalized SC. The coming future is very uncertain and challenging. Based on existing indicators, it is possible to create a picture of the barriers facing supply chains. Companies strive to minimize their costs by using limited resources. Future SCs will use fewer resources but will be more flexible to meet the needs of local and foreign markets. New technologies and trends are already being applied in supply chains and represent their secure future and progress.

Many companies are introducing IoT devices to improve the visibility of their SC. They can also use real-time information to proactively respond to customer needs, reduce downtime, and increase SC efficiency. Increasing the efficiency of SC can also be achieved with the use of artificial intelligence and 5G networks, high speed, and device density. Blockchain technology is seeing increasing application and development. Many are unaware of the value that blockchain technology brings, especially because of the importance of data and its integration into a single system. Cloud Computing represents the future, primarily due to data protection, availability of information at any time, security, reliability, and several advantages. Digital twins are becoming more and more popular and in use. The implementation of sensors in facilities, vehicles, or objects in any part of the SC and the collection of data from these sensors will enable the supply SC to run without disruption and with greater accuracy. Product life is getting shorter, and deliveries are more frequent, which leads to the main problem—increasing the number of vehicles and kilometers traveled. In the future, companies will need to develop a variety of supply chains to stay profitable and speed up processes to keep up with demand. SC flexibility is very important to meet certain changes, disruptions in implementation, and changes that are present in customers. Sustainability means that resources are used and spent in a way that will enable future generations to use them. Increasing emphasis is being placed on ecology and environmental protection. In addition, sustainability in the SC should be viewed from the perspective of the company's customers and profit, in addition to the environment and the planet. Another trend that is becoming more common is the reduction of human labor, which is being replaced by autonomous robots. Robotics is currently playing a major role in transforming supply chains. More and more companies are using drones and driverless vehicles to modernize their logistics operations.

Businesses and consumers can expect drones to become perfectly capable of delivering smaller packages in the future. On the other hand, driverless cars will still progress and will have the ability to make automated decisions in traffic. All the listed technologies that are already in use and future trends that are in great development are just the beginning of the improvement and optimization of SC.

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THE BENEFITS OF USING DRONES WITHIN LAST-MILE DELIVERY ACTIVITIES IN THE SMART SUPPLY CHAIN

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Abstract: *The aim of this paper is to consider the term of the last-mile delivery, as well as problems that may arise and their solutions. Last-mile delivery is the last step in the supply chain to deliver the goods to the end-user. This is the most important step in achieving customer requirements. There are different ways of realizing the last-mile delivery, such as conventional shopping, "click and collect", application of pick-up points and locker stations, home delivery, and in-car delivery. Last-mile delivery can be exposed to many challenges and problems that include outdated technology, COVID-19 regulations, increased CO_2 emissions, poor logistical visibility, etc. The use of autonomous drones is an attractive and modern way of solving the last-mile delivery problems. This paper discusses the use of drones as significant during the COVID-19 pandemic to deliver the necessary drugs and vaccines to some vulnerable areas.*

Keywords*: Supply Chain, LMD, Drones, Trends.*

1. INTRODUCTION

Market globalization and the use of new information and communication technologies have resulted in a constant need to increase the speed of goods flow throughout the supply chain (SC). Within the same, special attention is paid to the segment of delivery of goods to the final consumer. As a result, new solutions, business strategies, and concepts are created in order to overcome all possible obstacles and, at the same time, satisfy and meet the requirements of end-users in the most efficient way possible. All of the above speaks to the fact that more than ever, the emphasis and focus are placed on the end-user, that is, the pursuit of a high degree of customer satisfaction (Venus, 2019). In today's business environment, which is prone to rapid changes, legal persons and citizens require delivery in a short time to their home or company address, which can cause great challenges for their suppliers. In the SC, customers appear as the first point which

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generates delivery demands, and the last point in the chain, which evaluates the quality of the delivery service.
The successful realization of the service depends on a number of factors that occur from the very beginning of the realization of the service to the so-called last mile. Above all, high-level organization, cooperation, and synergy between all participants in the SC are required (Ewedairo, 2019; Borghetti et al., 2022).

The aim of this paper is to consider the concept of "last-mile delivery" (LMD) as a new type of service in the SC and the importance of that part of the delivery, as well as problems that may arise and their solutions. The concept of the LMD, its implementation, and potential problems will be discussed in the first section of the paper. The second part of the paper focuses on one of the LMD solutions, and it concerns the use of drones. The third part of the paper singles out some of the most common trends in this area.

2. THE TERM OF THE LMD IN THE SUPPLY CHAIN

The LMD in the SC refers to the distance it takes to deliver the product or service to the end-user, whether it is a direct delivery from a supplier, a distribution center, or any other entity in the SC. The transport of goods from point A to point B is something that existed in the earliest forms of developed society, while to this day, the number of these methods has only further developed. A large number of factors affect how, in what quantities, when, and from which place the goods will be transported to their final destination. What significantly influences the successful realization of this process is the successful realization of its individual segments, which can be called miles by one name (Ewedairo, 2019; Borghetti et al., 2022).

The last-mile represents the last step of the SC that needs to be carried out so that the goods undisturbed come from the sender to the recipient. LMD refers to the last distance that the delivery passes from the distribution center to the "home threshold" of the consumer. It is representative of the last step in the delivery process and represents the most critical section of the SC. Consequently, it is the most expensive (Ewedairo, 2019; Venus, 2019).

In addition to the LMD, which is mostly used to describe problems in the realization of delivery in the SC, there is also the first and middle mile. **The first mile** refers to the distance from the warehouse, i.e., from the center of the retail to the next hub, from where the goods will be carried on. The characteristic of this type of mile is that it has a different meaning for each of the participants in the SC. In the case of retail trade, the first mile would refer to the delivery of goods from local distribution centers to stores, while in the case of wholesale trade, the first mile would refer to the transport of goods from the manufacturer's factory to the distribution center. **The middle mile** means the distance at which the goods are supplied from the warehouses of distribution centers to the classic shops and retail facilities. End users come to these facilities in order to buy products. Figure 1 graphically shows the above types of miles, as well as their critical points (Ewedario, 2019).

Figure 1. Miles in the logistics (Ewedario, 2019)

2.1 Options for LMD logistical fulfillment

In the literature, numerous methods and options for achieving the LMD can be found. For the purposes of this paper, six options for the realization of the LMD have been singled out. It should be emphasized that this is not the final set of options, but only some of the most common and best-established examples. The first option involves **conventional shopping**. This means that the customer goes to the retail store in order to buy the product and he is responsible for the last part of the transport. The user can fulfill the LMD with own passenger car, bus, bicycle, on foot, etc. The next options include e-commerce. The second option is called **"Click and Collect,"** and it means that the user electronically orders the goods. This is an essential difference compared to the first option, which reduces the time of purchase. However, the similarity is reflected in the fact that the user also goes to retail stores to pick up the goods. Upgrading the previous option is the introduction of **pick-up points,** and this is the third option. The consumer orders the goods online and picks them up at those points that can be spread all over the country. The points are often placed within a walking distance from the user's home in urban areas, e.g. at supermarket entrances (Halldórsson & Wehner, 2020).

The fourth option involves the use of **locker stations,** which operate similarly to pick-up points. The main difference, as well as the advantage, is the independence of the time of picking up the goods from the working hours of the store. **Home delivery** is a frequent way to fulfill the LMD, which is the fifth option. It expanded during the COVID-19 pandemic. In this case, there is no private transport of goods. Delivery time must be coordinated between the customer and the logistics service provider. The latest among these options is **in-car delivery**—the sixth option. The end-user orders goods online and needs to park his car in a certain urban area during a defined time interval. The logistics provider locates the car and accesses the trunk in order to deliver the shipment. The user is responsible for the further transport of the goods (Halldórsson & Wehner, 2020; Ewedario, 2019).

2.2 LMD problems

The fact is that the LMD is the most critical part of the SC, which can be burdened with many problems and challenges. Table 1 presents the most common problems that may occur during the completion of the LMD (Correia et. al., 2021; Borghetti et al., 2022).

Table 1. The most common LMD problems (Correia et. al., 2021; Borghetti et al., 2022)

LMD problems	Brief description of the problem
Traditional routing models	Last-mile cost-effectiveness is linked to routing tools and strategies. Problems such as bad weather, congestion, and sudden road closures cannot be identified by "manual" routing methods.
Poor logistical visibility	It is necessary to establish synchronization between the provider's system and the system for tracking procurement and inventory. Otherwise, it may be difficult to track the location of the delivery truck.
COVID-19	Problems with the delivery and collection of shipments may be conditioned by regulations on social distancing.
Scaling delivery operations	It refers to the inability of companies to find a delivery manager during peak periods when their own funds are already engaged.
Firmly logistics processes	Processes are performed according to a predefined procedure, which means that there is no possibility to change the location and delivery time in progress.
Increasing CO_2 emissions	Heavy environmental pollution comes from transport. For this reason, it is expected of suppliers to replace existing and introduce new shipment delivery technologies.

3. AN EXAMPLE OF SOLVING THE LMD PROBLEMS

In the field of logistics, many researchers are facing the challenges of the LMD. The closer the product gets to the end-user, the higher the unit transport costs. In that part, the costs reach their peak at the completion of the LMD. The expansion of e-commerce, due to the COVID-19 pandemic, is leading to increased congestion, which encourages city authorities to strictly regulate traffic in urban areas. In addition, environmental and social issues should be taken into account, which largely dictate the way the LMD is conducted. One of the possible solutions is the use of modern technological solutions for Industry 4.0, such as drones (Borghetti et al., 2022; Sigari & Biberthaler, 2021). Figure 2 illustrates an example of an SC where a drone was used in the LMD.

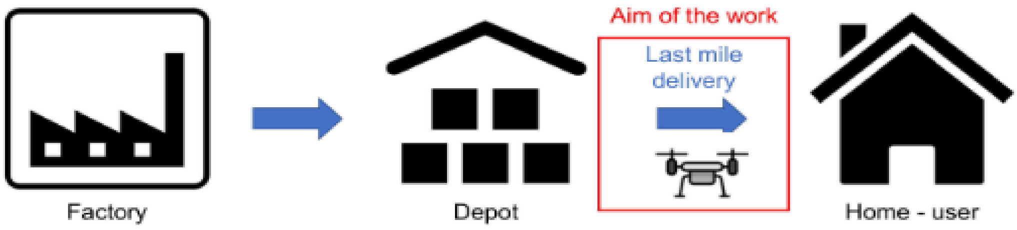

Figure 2. A schematic view of using drones within LMD (Borghetti et al., 2022)

Today, unlike in previous years when they were most often used only for military purposes, drones are increasingly attracting the attention and interest of logistics companies that provide goods delivery services. However, the use of drones in logistics processes and activities is still low. Continuous growth in the usage of drones is expected in the future. The current assessment includes the use of 20,000 drones for delivery. According to Gartner, more than a million drones are expected to be used in 2026 to deliver goods to retail facilities (Osakwe et. al., 2022). Since each SC is oriented towards meeting the requirements of end-users, commercial drones will be connected to mobile applications, which will be user-friendly. In this way, they can track the ordered goods, which reduces the delivery risk (Osakwe et. al., 2022; Borghetti et al., 2022).

DHL Express, a leader in international express delivery, and Ehang, a leading manufacturer of autonomous drones, have entered into a strategic partnership to achieve regular fully automated drone delivery. This endeavor came to life in 2019 in response to the challenges of the LMD in China's urban areas. The route is exclusively designed for DHL customers and covers a distance of 8 km between the DHL service center in Liaobu, Dongguan, and the customer's home. The use of drones for delivery overcomes complex road conditions; i.e., it can effectively avoid the congestion that is characteristic of urban areas (Osakwe et. al., 2022; Saraceni, 2021). This regular DHL service reduces delivery time in one direction from 40 minutes to just 8 minutes. Also, cost savings of up to 80% per delivery are achieved, with reduced energy consumption and carbon dioxide emissions compared to road transport. The Ehang Falcon drone has vertical takeoff and landing capabilities and provides high GPS accuracy, visual identification, intelligent flight route planning, and real-time network connection. It can transport up to 5 kg of goods per flight (Saraceni, 2021). The drones take off and land from the top of an intelligent locker, which is specially equipped for autonomous loading and unloading of delivery, as shown in Figure 3.

Figure 3. The drone takes off from the DHL intelligent locker (Saraceni, 2021)

The global impact of the COVID-19 pandemic has initiated an improvement in the SC like never before. The use of drones has become necessary for the transport of medical supplies because the delivery time between hospitals and clinical laboratories can be significantly reduced. In sub-Saharan Africa, during the pandemic, the delivery of necessary medicines and vaccines begins to work by using drones. It was necessary to ensure the availability of medical facilities in the shortest possible time, given that the infrastructure in that area was less developed. Also, with the use of drones, it is possible to provide tumor patients with the necessary chemotherapy drugs so they do not have to leave their homes (Sigari & Biberthaler, 2021; Saraceni, 2021).

From the aspect of ecology, research was conducted on the differences between the use of drones and delivery trucks in the LMD. Within a 4km radius, battery-powered drones have been found to consume less energy per package than delivery trucks. Given that road transport is responsible for 1/5 of harmful gas emissions on a global level, it is pointed out that drones deliver faster and with less impact on the environment. Like any new technology that is gradually being introduced, it encounters certain restrictions in replacing road vehicles (Stolaroff et al., 2018; Osakwe et al., 2022). The first restriction refers to the (non) acceptance of the use of drones by end-users for conducting the LMD (Osakwe et. al., 2022). The second restriction implies the existence of much larger storage capacities due to the limited range. Package size can also be a problem. Regulations related to the use of drones for commercial purposes include the obligation to register, possess a work permit, and carry liability insurance of up to 880,000 euros. It should be emphasized that regulations may vary from country to country. These regulations lead to a cost increase compared to other ways of completing the LMD (Stolaroff et al., 2018).

4. SOME ACTUAL TRENDS WITHIN THE LMD

With the raising of awareness about the importance of the degree of satisfaction of the end-user, certain trends appear in order to make that degree as high as possible. The first place is certainly the growth of electronic commerce, especially in the context of the COVID-19 pandemic. Due to limited movement and reduced contact between people, the only way to buy certain products was through the Internet and online ordering. This entails the requirements of users regarding the shortest possible delivery time, and most often on the same day.

4.1 E-commerce

E-commerce is the purchase and sale of goods, services, information, or products that take place with the significant use of modern information and communication technologies. The advantages of this method of purchase are: reduction of costs in various business segments; savings in in-service time because it responds faster to customer requests and achieves greater flexibility in customer supply; improving contact with consumers; improving business through increased revenue and access to new markets; increased labor productivity; and reduced commitment of business resources (Venus, 2019; Osakwe et al., 2022; Stolaroff et al., 2018).

4.2 Short delivery time

In the beginning, with the advent of e-commerce, the **delivery time** was approximately 5 days. However, later, that time decreased more and more, until today, when there is a delivery on the same day. The increase in this trend is a consequence of the fact that customers know exactly what they want and they wish to have the ordered product in their hands in the shortest possible time. It is also known that the shorter the delivery time, the higher the price. This fact is in favor of e-commerce companies because they are given the opportunity to make more profit and earn more on this trend. In general, customers want their LMD to "fit into life"—this includes offering a variety of options, including choosing the right delivery days, pick-up and packing cabinets, and more. According to research, more than 80% of customers today are willing to pay more for faster delivery, and meeting these expectations is the biggest challenge in LMD. One of the challenges of this trend is to ensure optimal use of vehicle capacity. As same-day deliveries generally involve small packages, the chances of fully utilizing vehicle capacity are becoming a problem, causing difficulties for logistics companies to make significant savings. Companies do not have that luxury, in terms of time, to wait for all orders that would ensure 100% utilization of vehicle capacity (Aćimović et al., 2020; Osakwe et al., 2022).

4.3 Crowdsourcing

Crowdsourcing is a trend that involves engaging a crowd or group of people for a common goal, hence the name "crowdsourcing". The common goal is mainly to introduce some innovation, problem-solving, or just greater efficiency. Crowdsourcing is driven by new technologies, social networks, and media. It can be applied and developed in various industries. Crowdsourcing is actually collecting information or opinions from a large group of people who send their data via social networks, the Internet, or applications on smartphones. Thanks to the Internet and social networks, organizations and companies are now closer to all stakeholders. Crowdsourcing the delivery of ordered products has marked a significant turnaround in LMD. Crowdsourcing logistics uses crowd workers to deliver the ordered item to the consumer as the cost of e-commerce providers themselves, providing LMD, is exceptionally high. Usually, crowd workers are a group of local and non-professional drivers who are willing to temporarily work for delivery companies and provide their assets (for example, their vehicles) to perform the parcel delivery. Crowdsourcing as a LMD concept is borrowed from sharing economy models like ride-hailing taxis (Uber and Lyft) (Correia et. al., 2021; Borghetti et al., 2022).

4.4 Consumer experience

The most important factor in the LMD process is the **experience and impression of the consumer** because it depends on whether the customer will remain loyal to the service provider or product. However, the expectation of every customer, online or not, is to have the best purchase experience and maximum satisfaction with their needs. All this must be a priority for logistics companies and their retail partners. The experience and opinions of already existing users of a certain product greatly influence the final decision of new customers on whether to buy something or not. As for the LMD process, consumer experience is the number one factor that drives innovation in this industry. Consumers have high expectations of the online shopping process itself. This refers to the ease and smooth flow of the purchase. The high satisfaction of end-users is reflected in their higher consumption as well as more frequent purchases. Such customers will better accept new ways of service. Apropos, a high-quality LMD service is the key to developing long-term relationships (Halldorsson & Wehner, 2020; Borghetti et al., 2022).

5. CONCLUSION

LMD problems are related to challenges that companies have to face from the moment an order is generated to the moment it is delivered to end customers. It has been shown that the use of modern software solutions and information and communication technologies can significantly contribute to the elimination and reduction of problems that occur during delivery to the end-user. Some of them are optimal route planning, organization, and engagement of human resources; determining the availability of stock levels; means of transport; insufficient efficiency and speed in delivery; and similarly. The LMD in the SC is becoming a special type of service, which is becoming increasingly important due to financial, environmental, and other issues. At the same time, it represents the last phase of the SC and the last step in the delivery process to the end customer.

One of the most modern solutions to LMD is the use of unmanned aerial vehicles or drones. The use of this technology at a higher percentage worldwide would lead to a significant reduction in environmental pollution, reduce the need for manual work, and increase the speed, reliability, and accuracy of delivery. However, in addition to numerous advantages, there are several disadvantages, such as the inability of drones to access all locations due to different legal regulations or unfavorable weather conditions, and it is not possible to deliver heavy deliveries. Although this type of delivery in trade is not very common in the world, the use of drones for these purposes is expected to increase. This would further contribute to certain trends emerging in the field of LMD, such as the rise of e-commerce, home delivery, and same-day deliveries, which are of particular importance during a pandemic. In the end, the method of realization of delivery depends on the users themselves, specifically on their expectations and needs. Therefore, the focus is on them, and they strive to achieve the highest possible degree of customer satisfaction.

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THE IMPORTANCE OF THE IMPLEMENTATION OF LEAN TOOLS IN THE AUTOMOTIVE INDUSTRY

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Abstract: *Just in Time and Just in Case are essential Lean technologies that offer significant benefits in a variety of supply chain management scenarios. Those technologies are the mainstays of the Lean concept's tools that help to reduce costs, increase profitability, and meet consumer demands. They aim to reduce all waste by eliminating all actions that do not add value to the product. The paper also discusses the Poka-Yoke system and Kanban cards in addition to these tools. The benefits of applying this approach are demonstrated by Volkswagen, which has used these technologies to greatly improve production processes and the entire company.*

Keywords*: LEAN, Automotive industry, JIT, JIC.*

1. INTRODUCTION

In the past, mass production dictated the conditions in the market. Everything that was produced could be sold. Today, supply is formed according to customer requirements and their wishes, which requires additional market research, not just serial production, without information on demand. If this system of production were to continue, it would result in high costs of production, stocks, storage, etc., which would increase the price of an individual product without good reason. In response to the increase in these costs, Lean was created. Forming the concept of Lean, as a solution to the problems of overproduction, downtime, and waiting, it was concluded that it is necessary to eliminate all types of waste. From this concept, Just In Time (JIT) emerged. Due to the possibility of production downtime using the JIT concept, a new tool, Just In Case (JIC), was developed (Jayaram et al., 2008; Monden, 2011). The main goal of Lean is to meet customer requirements, and the prerequisite for this is timely and accurate communication between employees, which is regulated by the introduction of the next tool, Kanban cards. All this is regulated, according to the hierarchy by the highest system and one of the main tools of Lean, the Poka-Yoke system. These tools, as well as how they work in the Volkswagen factory, will be discussed in more detail further below (Ohno & Bodek, 2019).

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2. LEAN TOOLS – GENERAL TERMS

The Lean concept originated at Toyota in the post-World War II period. It was created as a solution to improve production, following the example of the American company Ford. Lean is based on a philosophy that defines value from the customer's point of view and constantly improves the way value is created. Specifically, Lean is based on eliminating any use of resources that may cause the waste or that do not contribute to the end value for the client. This can be achieved through the proper functioning and work of each worker so that he realizes his full potential and contributes as much as possible (Ohno & Bodek, 2019).

Within Lean, there are seven types of waste: overproduction, scrap, transport, waiting, overprocessing, inventory, and unnecessary movements. Excessive production means the production of products that cannot be placed on the market with the excessive performance of operations, excessive documentation, etc. Wasting in the form of transport means unnecessary movement of material between processes due to, e.g., poorly conceived layout. Due to poorly planned production, there is a wait for the execution of operations, which creates additional costs (Monden, 2011; Ohno & Bodek, 2019). Waste as a consequence of excessive processing and excessive movements occurs due to poor product design, too many processes, unnecessary movements of workers, etc. Inventory, as tied-up capital in warehouses, certainly does not contribute to the final value of the product but increases costs, so this waste tends to be minimized. And the last type of waste is scrap, which occurs due to the interruption of the production process due to, for example, incomplete or inaccurate information, which stops the whole flow. The implementation of the Lean concept is done by standardizing all procedures and constant training and testing of employees' knowledge. Changes begin with defining the problem and then the target state. Until this goal is established, it is necessary to continuously monitor processes, manage them, and improve them in real-time (Dabić-Miletić & Božić, 2021; Jayaram et al., 2008, Lepadatu & Janoski, 2018).

3. LEAN TOOLS IN PRODUCTION

The company must be aware of its waste before implementing the Lean approach. If the wrong waste is defined, the wrong Lean tools will be used, providing no results. Some of the tools used are JIT, JIC, Kanban cards, Poka-Yoke system, 5S, Muda, etc. In the following paper, some of these tools will be presented as key in the implementation of the Lean concept in a company. These solutions may improve a company's profitability by up to 70%, increase productivity by up to 67 percent, and cut production costs by up to 65 percent (Leksic et al., 2021; Jayaram et al., 2008).

3.1 Just in Time

Many researchers believe that the source of inefficiency is overstocking and the accumulation of finished products. The tool most commonly used in such situations is JIT. JIT implies an approach/strategy that focuses on producing the required amount of required products at the required time. The JIT strategy coordinates raw material orders from suppliers directly with the production plan and program. The application of JIT in production refers to increasing the ability of workers to operate a larger number of machines and devices, as well as helping other workers in the event of interruptions and failures on the production line. JIT manufacturing systems reduce inventory costs because manufacturers receive materials and parts as needed for production and do not have to pay storage costs. Manufacturers are not left with unwanted inventory if the order is canceled or not fulfilled. One example of applying the JIT system is described by Toyota, a low-inventory automobile manufacturer that relies heavily on its supply chain to supply the parts needed to make automobile as needed. As a result, after receiving the order, the manufacturer orders the parts needed to assemble the automobile. For JIT production to succeed, companies must have continuous quality production, no equipment failures in machinery and equipment, and reliable suppliers (Lepadatu & Janoski, 2018; Ohno & Bodek, 2019).

3.2 Kanban

The Kanban system is used to improve the communication of all production lines. The system employees are as follows: Data on the type and quantity of units needed for production are entered on a card in the form of a label called "Kanban" and sent by workers of one process to employees of the previous process. In that way, the accuracy of the production process is achieved because there is information about where, how many, and which units are needed. The result of the application is that many processes in the plant are interconnected. This linking of factory processes enables better control and management of the required quantities of materials for different products. Sending information to the employees of previous processes gives them a clear picture in advance of the required quantities and time of production of individual parts. The following figure 1 illustrates the Kanban card (Thürer et al., 2022; Monden, 2011).

Figure 1. Kanban card (Thürer et al., 2022)

In the previous figure, it can see that the kanban card consists of several labels. The M4 mark indicates the route within the manufacturing process. A special mark on Kanban cards is WMI and VDS, which are parts of the vehicle identification number and consist of numbers and letters. On the card in Figure 2, the letter J in the WMI number indicates the geographical area of the manufacturer in this example, Japan. Other letters and numbers indicate engine types, models, and similar terms, and each manufacturer, for these and all other symbols on the card, has an internal list of unique markings (Thürer et al., 2022).

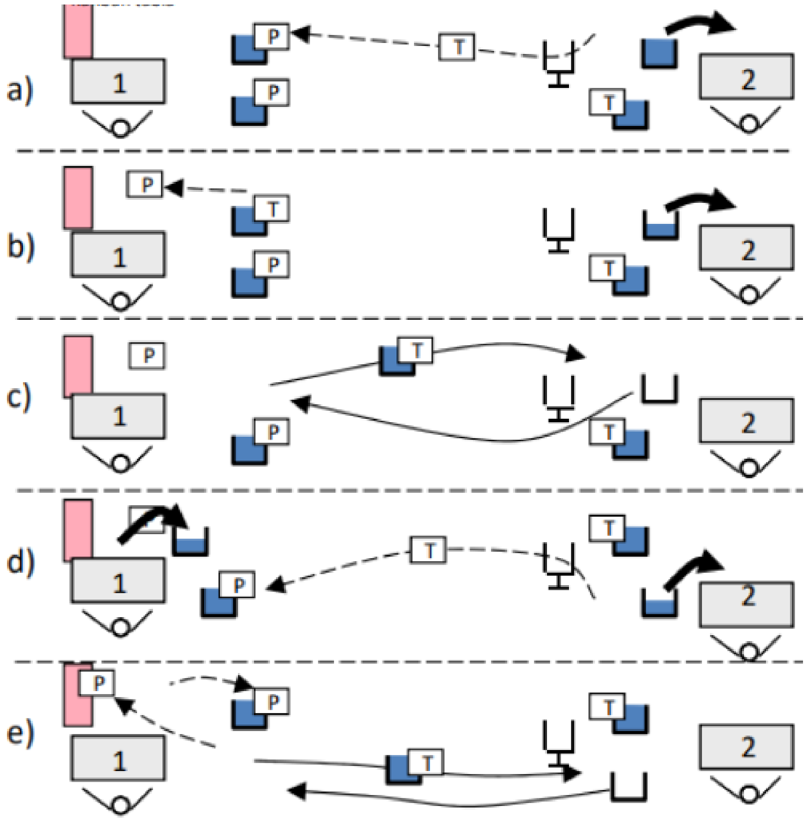

Figure 2. Two-card flow of Kanban system (Simeunović & Tomašević, 2022)

Figure 2 shows the two-card flow of Kanban. In the part of Figure a), the employees at Station 2 take the parts from one box. The transport card is placed in the Kanban card box and sent to Station 1 (transport signal), where the parts from the box are used. The employees at Station 1 take the production card (production signal) from the full box and add the transport card to that box, as seen in part of Figure b). In part of Figure c), it is shown that the employees at Station 1 send a box with a transport card to Station 2 (empty boxes from Station 2 are sent to Station 1). When one or more production cards are assembled at Station 1, production begins, as seen in segment d). Finally, he puts a production card in each full box, which indicates the beginning of the production of these parts (segment e) (Simeunović & Tomašević, 2022).

3.3 Just in Case

Another tool that will be described in this paper is JIC. The essence and significance of the JIC concept will be explained through a comparison with the JIT strategy. The JIC strategy is to maintain a minimum level of inventory with the goal of never running out. In essence, it can be costly if inventory is wasted, but the global nature of supply chains sometimes makes JIC a more appropriate approach than JIT. The goal of JIT is not to keep stocks low, but to improve efficiency and reduce costs and storage space. The parts are delivered to the mounting strips a few moments before they need to be installed, which allows the products to be made to order. This works well if the parts are manufactured in-house or by local suppliers who can guarantee delivery on a daily basis. While JIT requires suppliers to be able to provide parts on time, JIC only functions if companies continuously predict part demand and transmit information to suppliers in real time. This can ensure that suppliers optimize production to meet demand and prevent companies from holding too much or too little inventory. Table 1 shows the basic differences between the JIT and JIC strategies (Lepadatu & Janoski, 2018; Jiang et al., 2022).

Table 1. Differences between JIT and JIC (Jiang et al., 2022; Monden, 2011)

	Just in Case	**Just in Time**
Main goal	efficiency for end-users	efficiency for all entities
Production	MRP (material requirement planning)	centralized forecast
Planning and control	optimization of the existing system	demand planning
Quality	error detection	error prevention
Focus on performance	production plant efficiency	system efficiency
Suppliers	multiple, remote, independent	one or two sources; within the production system
Stocks	part of the system	strives for elimination

3.4 Poka-Yoke system

Toyota Production System introduced the Poka-Yoke system in the 1960s to prevent human error. The goal of Poka-Yoke is to detect errors and take corrective action. It is hierarchically above the previously mentioned systems, which means that it controls all production processes. This system helps all employees avoid mistakes. Regardless of the type of technology used, the goal is to detect and eliminate abnormal conditions that lead to the prevention of product defects. This system stops the whole flow by detecting an error. With the development of Industry 4.0 and the application of its solutions, such as Cloud, Big Data, Blockchain, Digital Twin, Artificial Intelligence, etc., everyone is making Poka-Yoke's work easier (Lv et al., 2022; Lepadatu & Janoski, 2018).

The Poka Yoka system can also be used to prevent the causes of errors and control, which decides whether to adopt or reject the product. So, her task is to detect the error as soon as possible. By analyzing all processes and their continuous improvement, a "zero defect" is achieved. Detecting errors before defects in a product that has already reached the user is the main goal of this system. Errors should be detected as soon as possible and eliminated as much as possible, i.e., eliminate the cause of the same so that mistakes do not recur. The basics of implementing the Poka-Yoke system are preventive controls and warnings (Widjajanto et al., 2020; Lv et al., 2022).

By introducing the technique, the company is guided by the following principles: Defects are most often the result of human error. It should be pointed out that these mistakes happen without the worker even being aware of them. The causes are mostly poor communication or identification, poor training, etc. The solution to poor communication and incomplete information is certainly Kanban cards, which in themselves improve the exchange of information between employees. All errors made in the company are recorded and then analyzed. Most of them can be prevented by using Poka-Yoke techniques (mistakes are answered quickly and in the short term, which reduces their frequency). The techniques used are simple, do not require the intervention of an engineer, and are cheap and efficient (Lv et al., 2022; Monden, 2011).

4. SOME BENEFITS OF IMPLEMENTATION OF LEAN TOOLS IN THE AUTOMOTIVE INDUSTRY

The goal of this paper is to look at specific Lean tools and analyzing of their using in practice. An example of the use of Lean tools in the automotive industry is provided for the purpose of this research. The following is an example of how Volkswagen employed Lean techniques to minimize waste, boost productivity, and reduce the time it takes to produce a unit of production.

Many organizations have worked to optimize production processes after understanding that global market demands, particularly increasingly complicated client expectations, are setting new production flexibility criteria. Volkswagen, one of Europe's largest automobile manufacturers, has implemented a Lean manufacturing approach. However, the organization continues to experience issues as a result of the lack of preventive control systems (Lepadatu & Janoski, 2018; Lepadatu & Janoski, 2018).

The company's management saw problems in the functioning of the production process due to the occasional downtime of the manufacturing process. The reason for this is the decentralized storage system, which is the physical distance between the storage of components and the manufacturing process. Namely, the layout of the Volkswagen complex is organized as follows. At the production plant in Emden (Germany), the inventory of materials needed for production is located in the complex itself, because the dimensions of the production plant allow keeping the inventory in the same place where the manufacturing is. In other cities, storage facilities with inventory are located at a distance of about 30 minutes from the factory. In the production facilities themselves, there is a certain amount of inventory. However, when that quantity is not enough, delivery is made from the storage. This type of filling can cause downtime on production lines (Jiang et al., 2022; Thürer et al., 2022).

As it was concluded, a small amount of material is kept in the production plants for certain manufacturing processes that require a certain level of inventory at a given moment, and about 2 hours are needed to fill the hall with new components, assemblies, etc., for the next cycle. In such conditions, the system does not allow the production process to stop and the requirements for inventory of materials to accumulate. The company's management has applied the JIC concept to solve problems when a certain level of inventory is required in the production plant itself. This prevents the manufacturing line from stopping due to a lack of materials. However, this concept requires additional space. When that is not possible, the managers of the companies choose JIT, in case the problem of the distance between the storage and itself is solved. Since delivery alone requires less cost than downtime due to lack of inventory, this concept is effective for factories whose warehouses are far away (Jiang et al., 2022; Thürer et al., 2022).

The implementation of JIT and JIC strategies maintains the level of inventory so that the required components are at the right time, in the right place, and in the right quantity. In addition, without the use of the Kanban method, all production systems would be unable to coordinate and synergize.

The Kanban system provides information such as the exact time at which a particular product part will arrive at a given production line. However, if an error occurs during the installation of a part of the automobile that is not intended for that model, quality control finds errors only at the end of the process, which includes the possibility of several consecutive errors. As a solution to this type of problem, the implementation of the Poka-Yoke system is proposed. In this way, the company would take full advantage of Lean production and establish a balance between quality and timely customer satisfaction (Jayaram et al., 2008; Lepadatu & Janoski, 2018; Thürer et al., 2022).

5. CONCLUSION

The implementation of the Lean concept contributed to an increase of efficiency in Volkswagen's car industry. The manufacturing facilities are organized so that communication is done via Kanban cards. In this way, the information is timely and accurate, which prevents human error in the initial stages of production. Volkswagen's production system has its own storage within the production plants, which enables the application of the JIT business concept. However, if there are no conditions for this type of supply of inventory, the same effect is achieved by organizing production so that the storage is up to 30 minutes away from the manufacturing halls. In this case, the JIC concept is applied, which means that the optimal amount of stock is held, obtained by continuous research of market demand. Above all production processes, there is the Poka-Yoke system, as a tool to control and correct any defects that may occur.

The goal of this system is to stop the flow of the process immediately after detecting the error since it has been established that the occurrence of a defect at the beginning affects all further processes until the end of a given series. Before the introduction of the Poka-Yoke system, bugs "accumulated" and were noticed only at the end of the series, which increased costs as well as production time. With the introduction of Lean, Volkswagen has increased profits while satisfying customers, improving business, and reducing costs. The contribution of the Lean concept can be seen in the production systems of the automotive industry, but it can also be applied to all manufacturing companies that strive to be leaders in the market. Implementation requires initial investment and standardization of all processes and methods of work, but it significantly contributes to the improvement of business and the reputation of the company from the very beginning of the application of this concept.

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LOGISTICS PROCESSES AND CHALLENGES IN AIR TRANSPORT OF TEMPERATURE-CONTROLLED GOODS

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Abstract: *The two basic parameters that determine the choice of mode of transport are the type of goods and the speed at which they must be transported. Despite the high costs and space constraints, the transport of goods by air is becoming an increasingly common choice of customers. This paper emphasizes the transport of perishable goods by air, which requires maintaining an appropriate temperature level in order to maintain good quality of the goods. Efficient implementation of all logistics processes and their continuous monitoring and control affect the success of the transport of this type of goods. The aim of this paper is to point out possible problems when transporting goods by air and the advantages of using different types of cargo handling units, which greatly facilitate the maintenance of the required temperature level, as well as conditions and recommendations for their transport by air.*

Keywords: *supply chain, logistical challenges, temperature regime*

1. INTRODUCTION

The growth of global trade over the last few decades has led to innovations that have made significant changes in business, primarily in equipment and infrastructure in warehousing, handling and transportation of cargo. Due to its speed and safety, air transport is becoming more and more present, especially when transporting cargo that requires special temperature regimes. It showed its importance to a large extent during the Covid-19 pandemic when a large number of medical devices and equipment, drugs and vaccines were transported by this mode of transport.

This paper consists of three parts and is organized as follows. The first section of the paper defines the cold supply chain, what it represents and what its requirements are, and then gives a brief overview of the groups of goods that are usually transported as well as the required temperature regimes for transporting each of them. After that, the types of cargo handling units that meet the requirements in terms of standards and regulations for the transport of goods under temperature regime, the so-called unit load device (hereinafter ULD), IATA (The International Air Transport Association) and their marking system, as

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well as ULD identification codes and aircraft types in use, are described. Due to the specifics of goods under the temperature regime, there are a large number of different requirements in terms of logistics processes (primarily processes of storage, handling, packaging, transport, monitoring and traceability), which are described in detail in another chapter. The last chapter presents an example from practice, i.e., the challenges that the company Milšped (Belgrade) faces when organizing the transport of pharmaceutical products, which in the previous period due to the Covid-19 pandemic were the most common representatives of goods under temperature regime. Each challenge is accompanied by the way in which the company Milšped solves potential problems, and at the very end, the conditions and recommendations for the transport of these products are given.

2. COLD SUPPLE CHAIN

With a better standard of living, especially in the developed countries of the world, people are more aware of the quality and need to purchase products that are fresh and available only in certain parts of the world. These products can be called perishable goods, which includes all goods that will spoil or lose their quality during a certain period of time if they are exposed to unfavorable temperature, humidity or other environmental conditions. The growing need for the safe transport of products sensitive to temperature changes over long distances has led to the emergence of cold chain logistics. A cold chain is a temperature-controlled supply chain consisting of refrigeration plants for production, storage and distribution supported by equipment that can constantly maintain the required range of low temperatures to ensure the quality and functions it has (Menon, 2021).

2.1. Types of goods and their temperature regimes during transport

Depending on the type of products transported through the cold chain, specific temperature standards apply. For products such as fruits and vegetables, breach of integrity can lead to damage such as softening, bruising, unwanted ripening, discoloration, texture degradation as well as the development of rot and mold. When it comes to pharmaceutical and medical products, the inappropriate temperature can lead to loss of function and make these products unsafe to use. Although the optimal transport temperature varies from product to product, 5 basic temperature standards have been identified that are most commonly used (Figure 1) (Transportgeography, 2022).

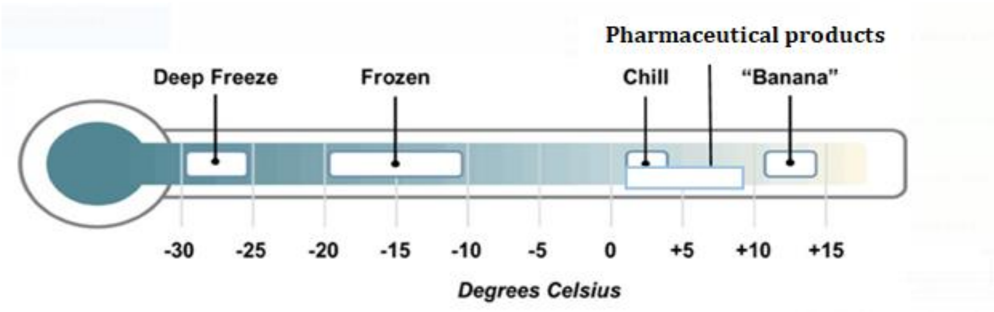

Figure 1. Basic temperature standards (Transportgeography, 2022)

Table 1 shows the types of goods transported under the temperature regime.

Table 1. Temperature range for transport of certain types of goods (Transportgeography, 2022)

Temperature range	**Type of goods transported under the specified temperature range**
Deep freezing (-30 to -25℃)	1. Seafood (especially shrimp) 2. Ice cream
Frozen (from -20 to -10)	1. Frozen meat (beef, pork, poultry) 1. Frozen bakery products (cakes, bread, etc.)
Chilled (from 2 to 4℃)	1. Fruit 2. Vegetables 3. Fresh meat
Cooling (from 2 to 8℃)	1. Pharmaceutical products (drugs, vaccines) 2. Medical products
Chilled (from 12 to 14℃)	1. Fruits - whose ripening is controlled during transport, most tropical fruits such as bananas, oranges, pineapples, etc.
Temperature ranges from 15 to 25℃	1. Flowers 2. Certain pharmaceutical products such as various types of vitamins

2.2. Types of aircrafts and ULDs when transporting goods under temperature regime

In the cold chain, time is of the essence to ensure that products arrive at their destination while still offering maximum quality and shelf life. As a result, many of these goods are now transported by air. Passenger and cargo aircraft are used for transportation. Passenger aircraft are generally more frequent, cheaper and more accessible, which are also the main reasons for their use for freight transport. Cargo aircraft are specially designed for the transport of various cargoes and, accordingly, enable better temperature control, additional capacities and smaller inspections. On the other hand, the flight schedule is much rarer compared to passenger flights, they provide a smaller choice of locations, are more expensive and often wait for filling capacity to start the flight, which is extremely unfavorable for perishable and sensitive goods (Baxter and Kourousis, 2015).

ULDs are very often used for the transport of goods under a temperature regime. ULD is a cargo handling unit for grouping and retaining cargo in air transport. It is designed to be directly attached by a cargo loading system to the aircraft and thus becomes part of the aircraft structure during flight. The design largely depends on the purpose, and the type of aircraft in use (whether they are wide-body or narrow-body). They can be certified or not. Certified ULD is one that is considered an integral part of the aircraft, corresponds to the fastening systems in the aircraft, and is structurally designed to ensure i.e., strengthens the cargo and thus protects the structure of the aircraft and other fastening systems from damage. Certified ULD has approval, issued by the state agency responsible for aviation, which confirms to the manufacturer that ULD meets all the safety requirements of the aircraft in which it should be transported. While non-certified ULDs can only be loaded into an aircraft compartment with certified cargo securing systems, in accordance with the aircraft manufacturer's instructions and weight limits (Jovanović, 2017).

When transporting goods under a temperature regime, ULDs can be used in 2 ways:

Standard ULD whereby the goods must be packed in an appropriate manner in various specialized packages with the possession of dry ice or gels to maintain the temperature of the product during transport, liquid nitrogen, eutectic plates and insulation covers. In this way, ULDs provide protection against damage during handling, facilitate loading and unloading and make it faster, and protect goods from atmospheric precipitation, while proper packaging maintains the desired temperature (Baxter and Kourousis, 2015).

Refrigerated ULDs allow the desired temperature to be maintained within the load unit itself, these containers operate using an active temperature-controlled system based on compressors, refrigeration or electric heating equipment. These containers also have an insulated shell that helps maintain the proper temperature during the transport cycle, while the temperature can be checked and monitored at any time with the help of innovations such as RFID, and also the condition of the battery can be checked at any time. The temperature range varies from -20 to +25°C according to the type of goods being transported. It is also possible to work on rechargeable batteries, which can last about 35 hours and can be charged in a standard AC outlet (Baxter and Kourousis, 2015).

One of the options during transport is that the aircraft itself has the ability to achieve a certain temperature regime with the help of various cooling devices and systems. At the same time, a very important thing is the altitude at which the aircraft flies. The higher the flight altitudes, the lower the temperatures, and thus the internal temperature in the aircraft can be disturbed and, in that way, damage the goods being transported. For these reasons, it is recommended that when transporting goods under a temperature regime, flights at lower altitudes should be realized (Baxter and Kourousis, 2015).

Chapter 17 of the IATA Perishable Goods Ordinance entitled “Air Transport Logistics for Time and Temperature Sensitive Health Care Products” specifically addresses the issues of temperature control management identified by industries. The chapter describes in detail the requirements and standards for the transport of weather and temperature-sensitive medical air cargo shipments, including the mandatory use of the Time and Temperature Sensitive mark which must be affixed to all shipments reserved as time and temperature-sensitive cargo. It has been in force since July 1, 2012 (Baxter and Kourousis, 2015).

ULDs must have a valid three-letter IATA ULD marking system (Jovanović, 2017):

- First letter (position 1): ULD category (whether certified; part of the structure or not; whether there is equipment for cooling, insulation or temperature control; what type of ULD is in question: pallet, container, net, needle),
- Second letter (position 2): base dimensions,

- Third letter (position 3): ULD contour and compatibility with loading and securing equipment (e.g., if "N" then it can be manipulated with a forklift).

In addition to this, IATA also has its own identification codes for ULDs, which consist of 9 or 10 elements, which are arranged as follows (Jovanović, 2017):

- Positions 1-3: basic nomenclature of ULD (category, base dimensions and contours/compatibility),
- Positions 4-7 (8): ULD serial number, consisting of four or five digits,
- The last two positions: the alphanumeric designation of the ULD owner.

3. LOGISTICS PROCESSES IN THE COLD CHAIN

There are countless requirements that need to be met in order for the logistical processes (storage, packaging, transport, handling, etc.) for goods under temperature regime in air traffic to take place properly. Each type of goods that is under the temperature regime has its own specifics and accordingly different requirements. Some of these requirements, observing the logistics processes, are explained in more detail below.

1. Storage - Most of the cargo delivered to the airport does not stay long. Related to this is the fact that a large number of warehouses are quite simple and provide simple services, especially when it comes to less frequent airports or which are classified as an alternative in a country. Newer generation airports with modern warehouses have loading stations (ramps) in order to speed up the process of truck movement and minimize the time of unloading goods, after which the goods are sent for further security checks and procedures. Warehouses are always divided into parts intended for goods to be exported (where there are large areas for scanning, an inspection of goods, palletization and collecting cargo for certain flights) and goods imported into the country (where there are offices and premises for inspection reviews, in order to facilitate customs clearance procedures and separate cargoes and their loading on trucks). Perishable goods require specific conditions in the warehousing sector as well. The warehouses where this type of goods is located are under constant supervision and with the appropriate temperature regime in order to maintain a cold chain between the truck and the aircraft. This allows exporters to store perishable items for as long as possible in the event of a flight delay or if they miss the shipment for some reason (The World Bank Group, 2009).

2. Manipulation - Cargo handling operations at airports include preparation of cargo shipments, loading and unloading of aircraft, and cargo transfer between warehousing and land transport. Outgoing cargo preparation includes cargo consolidation, pallet and container preparation, inspection and documentation. The goods are placed on pallets and in ULD containers before loading into the aircraft, in order to facilitate the procedure. Preparations for the importing load include customs and other regulatory procedures, as well as deconsolidation. For goods that are classified as perishable goods, it is necessary to provide refrigerators, i.e., rooms where the temperature will be maintained in accordance with the requirements of the delivered cargo. The inspection is mainly performed at the airport, including scanning, visual and other checks. Personnel in charge of cargo handling at the airport should ensure that the processes are carried out efficiently and safely so that there are no changes in the goods in relation to the condition in which they were received (The World Bank Group, 2009).

3. Packing - in order for the goods to reach the airport safely, continue their journey by air, and then be transported to the end-user, it is necessary to be properly packed in accordance with their characteristics. The type of goods determines the type of packaging to be used. In that sense, the packaging must provide adequate protection for the products inside it and prevent their possible degradation. For the purpose of ensuring and preserving the quality of the product, it is sometimes required that the product has both inner and outer packaging, in order to prevent contamination and spoilage of the product caused by external factors (sunlight, moisture, heat, insects, etc.). For example, some countries require a fine plastic net that is placed over a pallet as an external lining to prevent pests. They are used for fruits, vegetables and flowers. The second type is polymer foils wrapped around the pallet to protect the shipment from moisture and prevent leakage if the products are liquid or with a high percentage of water in their composition (Vietnam Airlines and IATA, 2022).

Common packaging for perishable goods used in air transport includes (IATA, 2022):

1. Fiberboard packaging,
2. Expanded polystyrene (EPS) packages,
3. Solid plastic packaging,
4. Flexible plastic packaging,
5. Packages for vacuum and modified atmosphere,
6. Wooden packaging,
7. Metal cans and canisters.

After the packaging is selected, in order to maintain the temperature level according to the requirements of the goods that are the subject of transport, it is necessary to use a refrigeration device or special refrigerated containers that are specifically designed for this purpose. Thanks to them, the goods remain unchanged in condition, shape and quality.

4. Transport - during transport it is of great importance to know what type of goods is transported, and then what conditions and equipment are required during transport. Most refrigerated, semi-refrigerated and fresh products are stored and transported at temperatures between -1.5°Cand +14°C, depending on the type of product. However, the products can be transported even if they are completely frozen. Perishable products such as flowers, fruits and vegetables can easily transfer their scent from one product to another, that is, contaminate the products in their vicinity, as is the case with vegetables and fruits that contain high levels of ethylene and affect their mature too quickly and thus endanger other goods (LTU International Airways, 2012).

For this reason, various specialized packaging is used for these products that belong to the group of perishable, as well as refrigeration devices, dry ice or gels to maintain the temperature of the product during transport. Dry ice is used to transport frozen fruits (such as berries), frozen vegetables, as well as food samples (various types of pastries). In addition to food, dry ice is also used for the transport of sets of COVID tests, as well as for some reagents, drugs and certain chemicals that are an integral part of medical devices. Another method of transporting goods sensitive to temperature changes is using thermo-gels (Figure 2). In contrast to dry ice, thermal gels are not treated as dangerous goods, but they are a more expensive solution, and they are packaged as a liquid refrigerant that absorbs heat and maintains a constant temperature. Liquid nitrogen is also used, which is used primarily for the transport of biological cargo (organs, tissues). It is extremely cold, it keeps items frozen for a long time. Eutectic plates are also called cold plates, similar to gel packs, but they can be reused, which is their advantage (Heap, 2006).

Figure 2. Packaging of goods a) gel b) dry ice (FedEx, 2019)

5. Monitoring and traceability – pharmaceutical companies, restaurants and retail food chains go in the direction of adopting visibility monitoring solutions in order to gain visibility and control in the entire supply chain. Data on delivery, location, data on records and traceability of the cold chain are easily accessible and very important because they provide immediate insight into the movement of goods, the condition of goods during transport and their location. The existence of software that determines exactly where the cargo is at all times and the ability to access this information via mobile phone or computer speaks of technological progress and is crucial for the next generation of services to be provided. Built-in sensors, including light, temperature and barometric conditions, monitor the condition of the product during its journey, triggering an alert if certain errors appear on your computer or mobile phone. GPS tracking allows stakeholders to know when products have left the warehouse and when they have arrived at their final destination. Therefore, logistics providers are increasingly investing in meeting visibility requirements. The number of points of contact is increasing, and knowledge of what is happening at each of these points of contact strengthens data for stakeholders to mitigate risk, improve logistical performance and standardize their metrics (Rodrigue and Notteboom, 2016).

4. CHALLENGES IN THE TRANSPORT OF GOODS UNDER TEMPERATURE REGIME - EXAMPLE OF THE COMPANY MILŠPED BELGRADE

Through a wide network of agents, Milšped is present at commercial airports in over 150 countries around the world, making sure that customers' delivery, routing and handling requirements are met. The range of products for which they organize import or export is very wide. The goods that stand out the most when importing and exporting, and also belong to the temperature-controlled goods are pharmaceutical products. Some shipments of pharmaceutical products must be delivered within certain time frames in order to protect their value. Others are fragile products and require special handling.

The most often problems that occur during air transport are the following:

- **Improper storage temperature**- before bringing the goods into the warehouse, it is necessary to determine the appropriate temperature for the same. According to the words of the manager N. Kolundžija, first, it is defined which pharmaceutical products are in question, whether they are drugs that are stored at temperatures from 2 to 8°C. Vitamins are stored at relatively higher temperatures. Accordingly, the place in the warehouse is agreed upon, whether it will be some remote positions where the temperature is lower than in other parts of the warehouse, or it will be necessary to put the goods in the appropriate refrigerators.
- **Discontinuous use of transport equipment -** the consignor may try to reduce costs by avoiding temperature control on less critical journeys, which is completely unacceptable for this type of goods that require continuous cooling, especially on parts of the road where outside temperatures are high (Heap, 2006).
- **Loading problems** - during loading, a larger number of units is usually brought in than must be loaded into the aircraft at once. In this way, one part of the shipment remains directly exposed to atmospheric influences. In order to prevent the deterioration of this product, it is necessary to protect the units from direct impact by covering them with blankets (insulated quilts can be wrapped or placed over the load and used to maintain a constant temperature, so that frozen items will remain frozen for a long time). Also, there is a problem that the goods are stored earlier than necessary and then waits for loading, where it is again exposed to the mentioned conditions. It is necessary to draw the attention of the warehouse workers to the goods in question in order to avoid unnecessary situations that could be dangerous to the quality of the goods.
- **Packaging errors**- they are very rare for goods that require a temperature regime, while they are very common for general cargo. However, before placing the goods in storage, it is necessary to check whether the packaging is appropriate and whether all regulations and recommendations have been followed (Heap, 2006).
- **Flight cancellation -** flights can be canceled for various reasons (failure, weather conditions, etc.) and in that case shipments that are under temperature regime suffer the greatest consequences, both due to the short lifespan and the inability to maintain the required temperature at the airport until conditions are met for shipping goods. The costs caused by these problems are extremely high. This problem is sometimes unavoidable when it comes to weather problems, but the technical correctness of the aircraft and its crucial parts is something that can be influenced through continuous checks and tests before the aircraft takes off.
- **Delivery Delay -** related to the previous problem, in the case of connecting flights, there may be delays, and thus the delivery of goods will be after a defined time, which again entails high costs. These problems can be mainly influenced, since they are a consequence of delays in operations that precede the transport itself - checking and completing documentation, loading and all other manipulative activities. Constant monitoring of the execution of these operations creates the conditions for these activities to be performed on time and in that way to avoid all possible delays.

When it comes to the conditions and recommendations for the transport of pharmaceutical products by air, the following stand out (Hyde, 2020).

Falling demand for air cargo and combined passengers is leading to two problems for the pharmaceutical industry. As air cargo space becomes even more valuable and a dwindling resource, there are measures that can be applied to mitigate reduced capacity. For example, temperature-controlled packaging systems should be at the forefront to reduce bulk density, providing better insulation performance and materials that can significantly improve volumetric efficiency. However, packaging systems currently available to reduce bulk density are usually more expensive unless reused, which cannot always be effectively achieved for both financial and environmental reasons. The pharmaceutical packaging industry should carefully consider the installed capabilities of aircraft to control temperature, which could make lower quality packaging materials more acceptable. Aircraft facilities also need to be synchronized with the conditions on the ground, and this can be a problem in less developed regions of the world. When it comes to pharmaceutical packaging, one size does not suit everyone - nor should it. Packaging manufacturers are expanding their product portfolios to enable the selection, qualification and application of the most efficient solutions in global supply chains. Making the right choices and performing the necessary qualifications can be difficult, but this is a challenge that needs to be faced in order to responsibly use dwindling resources. This can be a problem in less developed regions of the world. One of the most important recommendations is that pharmaceutical products in air transport should be marked with regular labels for pharmaceuticals (PIL - Pharmaceutical products), and not perishable products (PER - Perishable), in order to properly manipulate them and avoid problems in communication.

Standardization - In order to ensure efficient management of pharmaceutical products, it is necessary to have appropriate standards that will facilitate business for all participants in the chain. Working with stakeholders and regulators in the aerospace industry, IATA has created the Center of Excellence for Independent Validators in Pharmaceutical Logistics (CEIV Pharma) to help organizations and the entire air cargo supply chain get on the right track to excel in pharmaceutical handling. CEIV Pharma addresses the needs of the industry for safety, security, compliance and efficiency, by creating a globally consistent and recognized certificate for the handling of pharmaceutical products. By establishing a common basis based on existing regulations and standards, this certification ensures international and national compliance in order to preserve the integrity of the product, while addressing the specific needs of air cargo (Milšped, 2022).

5. CONCLUSION

Based on what has been said so far, it is clear that among the numerous requirements that need to be met, when it comes to transporting goods under temperature regime by air, the main ones which stand out are providing appropriate technology, which with its advanced systems will support the implementation of this and all other processes arising from the transport of goods; training of employees and their understanding of the importance of the positions they hold and the jobs they perform at the level of the entire supply chain; and finally - standardization, which is the basis for solving all the problems caused by irregular business practices and at the same time and opportunity to balance such processes. Transporting products under a temperature regime is a challenge for the airlines that accept them for transport, considering that transport can also be viewed as a phase in which the goods behave as if they were in a warehouse. By applying newer solutions, such as special refrigerated containers, individual refrigeration devices and materials used to maintain the required temperature level, the environment in the aircraft is successfully simulated in which the goods remain unchanged and quality. In this paper, challenges with which the participants in the realization of the process can face, were observed. The focus is on planning and implementing these processes and ways to overcome the problems that arise, while respecting all the conditions set by the goods with their characteristics, on the one hand, and airlines that have their own requirements and are responsible for shipments during transport, on the other hand. As there is always a need to go in the direction of finding better solutions compared to existing ones, airlines will constantly strive for optimal implementation of all logistics processes (from warehousing, handling, all the way to monitoring) and the application of new technological solutions that will adequately respond to the set and increasingly complex requests of clients. What is certain is that preserving the quality and integrity of goods will always be an imperative for all participants in the supply chain, no matter with what mode of transport goods are being transported.

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