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THE SELECTION OF PALLET TYPES BY RAW MATERIAL 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",

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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

$$X = \left[x_{ij}\right]_{mxn} = \begin{bmatrix} x_{11} & \dots & x_{1n} \\ x_{21} & \dots & x_{2n} \\ \vdots & \dots & \vdots \\ x_{m1} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

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:

$$x_j{}^* = (x_1{}^*, x_2{}^*, \dots, x_m{}^*) \tag{2}$$

Where:

$$x_j{}^* = \frac{\sum_{i=1}^{m} x_{ij}}{m} = \left(\frac{\sum_{i=1}^{m} x_{i1}}{m}, \frac{\sum_{i=1}^{m} x_{i2}}{m}, \dots, \frac{\sum_{i=1}^{m} x_{im}}{m}\right) = (x_1{}^*, x_2{}^*, \dots, x_m{}^*) \tag{3}$$

Step 3: Defining positive distance (PD) and negative distances (ND) from an average solution.

$$PD = \left[pd_{ij}\right]_{mxn} \tag{4}$$

$$ND = \left[nd_{ij}\right]_{mxn} \tag{5}$$

These values should be determined concerning the benefit or cost type of criteria.

If a jth criterion is a benefit criterion, then positive distance $pd_{ij}{}^+$ is calculated as

$$pd_{ij}{}^+ = \frac{\max(0,(x_{ij} - x_j{}^*))}{x_j{}^*}, \text{j} \in \Omega_{max} \tag{6}$$

If a jth criterion is a benefit criterion, then negaitive distance $nd_{ij}{}^+$ is calculated as

$$nd_{ij}{}^+ = \frac{\max(0,(x_j{}^* - x_{ij}))}{x_j{}^*}, \text{j} \in \Omega_{max} \tag{7}$$

If a jth criterion is a cost criterion, then positive distance $pd_{ij}{}^-$ is calculated as

$$pd_{ij}{}^- = \frac{\max(0,(x_j{}^* - x_{ij}))}{x_j{}^*}, \text{j} \in \Omega_{min} \tag{8}$$

If a *j*th criterion is a cost criterion, then negaitive distance nd_{ij}^{-} is calculated as

$$nd_{ij}^{-} = \frac{\max(0,(x_{ij} - x_j^*))}{x_j^*}, \mathrm{j} \in \Omega_{min} \tag{9}$$

Step 4: Determine the weighted sum of *PD* and *ND* for all alternatives, shown as follows:

$$SP_i = \sum_{j=1}^{n} W_j \, pd_{ij} \, , i = 1,\ldots,m; \tag{10}$$

$$SN_i = \sum_{j=1}^{n} W_j \, nd_{ij} \, , i = 1,\ldots,m; \tag{11}$$

where w_j is the weight of the criterion *j*.

Step 5: Normalize the SP and SN values according to the formula.

$$NSP_i = \frac{SP_i}{max_i \, (SP_i)} \, , i = 1,\ldots,m; \tag{12}$$

$$NSN_i = 1 - \frac{SN_i}{max_i \, (SN_i)} \, , i = 1,\ldots,m; \tag{13}$$

Step 6: Calculating appraisement score (AS_i) based on each alternative's NSP_i and NSN_i:

$$AS_i = \frac{1}{2} \, (NSP_i + NSN_i) \, , i = 1,\ldots,m; \tag{14}$$

where $0 \leq ASi \leq 1$.

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 it was determined that Natron-Hayat achieves satisfactory results with two existing

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