UNDERGROUND SYSTEMS IN SERVICE OF CITY LOGISTICS

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Abstract: *The topic of this paper concerns the models of underground logistic systems in order to solve the logistics problems of urban areas. These systems contribute to the protection of environment and quality of life in the city, displacing logistic activities, primarily transportation, underground. However, the investment risk is large, profits uncertain and can be expected only in the long term. It seems that these projects will be realized only as a last option, when the possibility of expansion of the existing road system is depleted.*

Keywords: *underground logistics, urban freight transport, the advantages, disadvantages*

1. INTRODUCTION

Urban freight transport experiences a continuous growth, and expectations are that this trend will be continued in the future. The main causes of this are the trends in production and distribution which are based on the low level of supplies and precisely defined deliveries (Just In Time) as well as the growing trend of e-commerce and home delivery (Zečević & Tadić, 2006). In order to solve the problem and secure more efficient implementation of logistic processes and activities, various initiatives and conceptual solutions of city logistics have been defined and tested. Underground logistic systems belong to the group of the most radical and most demanding financial initiatives. In addition, the abovementioned group seems very innovative and takes into account the system of underground networks, the amount of investments and high level of automation (Tadić, 2014). Underground systems have been intensively analyzed since the end of the 20th century, even though the underground transport system has a 200 years long history. The first system for underground transport of telegrams and postal mail from the center to the branch office in London started its work in 1853. Few years later it was introduced in other European cities as well: Berlin (1865), Paris (1867), Vienna, Munich, Rome, Naples, Marseille etc. These systems can be very effective for solving the problems of urban freight transport. They can also reduce negative impacts on the environment and improve the quality of life in the city. This paper gives various models of underground logistic systems and describes main characteristics, advantages and disadvantages of some of the designed solutions.

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2. CHARACTERISTICS OF UNDERGROUND LOGISTIC SYSTEMS

All underground logistic systems are characterized by some of the following factors (Chenglin et al, 2014):

1) Municipal structures and the aspects of land use – reducing the use of land for road freight stations, parking lots and other facilities.
2) Freight efficiency – reducing urban freight costs and improving transport services, avoiding congestion on the highways during storms, rain, snow and other weather conditions as well as providing a higher level of service that is more reliable, safer and more accurate than existing transport based on the urban freight system.
3) The safety of road transport – reducing traffic accidents caused by trucks.
4) The city's social environment – reducing energy consumption, emissions of harmful gases, traffic noise and vibrations caused by trucks.

Underground logistic systems appear in (Visser & van Binsbergen, 2000):

1) Urban areas in order to deliver mail, merchandise, catering, stationery. The unit of the cargo is the size of a pallet. Testing of the system was carried out in the German cities of Utrecht, Leiden and Tilburg, then in Japan and London.
2) Within and between the industrial complexes, logistic centers and multimodal terminals such as airports and port complexes. Units of the cargo are pallets, shipping containers and aircraft pallets. OLS Schiphol in the Netherlands is an example of such a project.
3) Long-range transport of agricultural products, ore and solid waste. For this purpose, capsule-type piping systems have been developed and implemented in Japan, USA and Russia.
4) Transport of maritime containers to inland ports. The research has been conducted in the United States.

By analyzing the projects and studies on the underground logistic systems, Chenglin et al (2014) have distinguished three development models: the metro model, the model of pipeline cabins and the vehicle model.

2.1 Model of underground logistic system based on metro

This logistic system is based on the use of passenger subway system. The final part of the transport of goods to the customer and the generator flow is realized in the usual way. Pielage and Rijsenbri (2002), Liu et al (2008) investigated the possibility of using the passenger subway system for the transport of goods in the city and analyzed its cargo capacity. Zhang et al (2005) analyzed the experience of underground logistics systems in different countries and suggested construction of the metro for "dual-use". The functioning of this system is affected by the requirements of passengers and cargo flows.

2.2 Model of underground logistic systems based on pipeline capsules

This form of underground logistics is based on pipeline technology that involves the use of round or square capsules, cabins for transportation. The transport capsule has a function of cargo transfer only, whereas orientation, the control function or any other are excluded. Its control function is a passive one and it is executed over the rails and the wall of the tube. The rate of wear of facilities and equipment is very large, and the construction of the pipeline is very demanding. Qian and Guo (2007) suggested that this model of the underground logistic system should be divided into three categories: pneumatic, hydraulic and electromagnetic. Pneumatic and hydraulic pipeline capsules systems are used to transport mail, package, fruits, vegetables and other time-sensitive goods and materials. Hydraulic systems are also used for the transport of ground, sand, ore and other materials that can endure a long transportation (Chenglin et al., 2014).

2.3 Model of underground logistic systems based on vehicles

This concept uses special vehicles that use mainly batteries as their source of energy for underground transport realization, e.g. AGV (automatic guided vehicles) in the Netherlands and DMT in Japan (Chenglin et al., 2014).

3. EXAMPLES OF UNDERGROUND LOGISTIC SYSTEMS

All around the world, different systems for underground transportation of goods have been proposed and designed. This chapter gives basic characteristics, advantages and disadvantages of some of the designed and tested solutions of the underground logistics.

In the Japanese city of Sapporo, attempted solution for the problems of distribution of goods, such as: traffic congestion, negative impacts on the environment, delays of delivery, especially during the winter when the snow makes transportation difficult, consisted of a system of logistic integration of public service station in order to transport goods from the suburbs to the city center efficiently. Sapporo (1.9 million inhabitants) in northern Japan suffers serious logistical problems in winter when snow drastically reduces transport efficiency on the dirt-roads. The possibility of integrating the city's subway system with a conventional truck transport has been tested in order to facilitate the distribution of goods between the suburbs and the city center (Kikuta et al., 2012).

Carts (sized 500x900x700mm, with a gross weight of 60kg) that are descended to the platform of the metro station and transported by the urban metro system in combination with passengers were used for the transportation of goods. On the station closest to the recipient, i.e. the final destination of goods, the trolley is raised above the ground and, if necessary, further transported by usual road delivery vehicle to the recipient. The pilot project has demonstrated numerous benefits for residents, senders, recipients and carriers, logistics providers, out of which the following can be singled out: (Kikuta et al., 2012)

1) Those who are delivering can avoid traffic jams and reduce the delay by changing the means of transport from truck to the subway
2) The traffic density is mitigated and the urban environment has a lower CO2 emission because the number of operating trucks and unloading of vehicles decreases
3) Traders in the central underground complex can overcome shortages of goods through fast and frequent delivery
4) The office of public transport can increase revenue by providing cargo services outside the city rush-hour

The main disadvantage of the project is the fact that passengers and cargo are not spatially separated.

Planned underground logistic system in Tokyo involves application of hybrid vehicles that have the ability to move on the regular road infrastructure, as well as a separate rail infrastructure within the underground system. Research on the impact of building a system in central Tokyo with a 300 km long tunnel with 150 depots has shown that this system could attract about 30% of the existing road freight traffic, which would reduce NO_2 and CO_2 emissions by 10% and 18% respectively, and power consumption by 18%, while the average speed of traffic in the city would be increased by about 24% (Ooishi & Taniguchi, 1999). Although the use of the system significantly reduces the number of environmental and social problems caused by logistic activities, analysis of the economic feasibility of its implementation resulted in the inert rate of return which amounted to 10% in the case that the infrastructure is constructed by the public sector. The results confirm that the system is not self-sustainable and can be considered reasonable only if we take into account all the social and environmental benefits for the entire exploitation period.

Underground logistic systems have been the subject of researches in some European cities as well. Germany tested a prototype system based on capsules that move underground tunnels or tubes and that can carry two pallets (Beckmann, 2007). A similar concept has been developed in Italy. A prototype designed in 2006 involved a capsule transport capacity of one euro pallet. Since then, numerous researches and feasibility studies of this system have been conducted (Cotana et al., 2008). Underground logistic systems have been considered in several cities in the Netherlands. The pipeline transportation system (capsules system) for supplying market chains of books and nutritional products has been considered in Groningen. Also, feasibility study for the use of underground supply systems through the implementation of AGVs (automatic guided vehicles) was conducted for Utrecht, Leiden and Tilburg (Tadić, 2014). The concept of automatic guided vehicles moving through the underground tunnels at a speed of 20-40 km/h has been tested for the transport of flowers between airports in Amsterdam, the world's largest flower auction in Aalsmeer and the railway terminal Hoofddorp (van der Heijden et al., 2002).

The first ideas of development of the underground system OLS (Ondergronds Logistiek Systeeem) appeared in the Netherlands in the early 1990s. Deteriorating accessibility, due to traffic congestion, started to threaten the position of Schiphol airport in Amsterdam and Aalsmeer Flower Aution. In order to solve this problem and ensure sufficient transport capacity, with minimal impact on the environment, the concept of the underground transport system has been discussed. Shortly after, it became clear that the third connection was needed too, and that it implied linking international railway terminal near Hoofddorp. By using high-speed freight trains and connecting the airport, auctions and international railway with the help of an underground freight transport system, a trusted connection was created not only between the auction and the airport but also with the rest of the Europe. In 1995, private companies started to work on a feasibility study of the underground transport system of flowers, expensive goods, computer parts and newspapers between Schiphol airport and Aalsmeer flower stock exchange with a new rail terminal in Hoofddorp (Wiegmans et al., 2010). These areas represent the initial and final point of cargo flows and they consist of several terminals: Schipol airport – two to five terminals, Aalsmeer flower auction – one to three terminals, Rail terminal Hoofddorp – a single terminal.

Consumers deliver and pick up goods through terminals, and the OLS vehicles perform transport. The terminals have the role of a buffer for temporary storage of goods and they are connected with tunnels, 5 meters in diameter, which are positioned at a depth of 0-20m underground and they can be unidirectional or bidirectional. Terminals are placed at the level of ground's surface in order to reduce construction costs and facilitate interaction with regional clients. The system is fully automated and uses AGVs for transporting goods between the terminal and fully automated transfer station. Around 400 AGVs, sized from twenty to twenty-six feet and weighing about 10 tons circulate the system. The usage of AGV has certain advantages: less vehicles leads to lower transport costs; there is less chance for human error which improves system reliability. A complex system with several hundred independent AGVs which movement needs to be guided and managed is very complicated to organize. There is a possibility of delays and a high speed and reliability of the system are required (Wiegmans et al., 2010).

This concept combines the social benefits of placing traffic underground and the use of electric drive with the economic advantages of the unobstructed automated transport through infrastructure that is separated from the passenger transport. Economic benefits are demonstrated in almost direct delivery, 24-hour service, low operating costs and short feedback time. Social benefits take into account legal limits, which results in a reduction of noise, pollution, emissions, reduction of the energy consumption, reduction of CO_2 emissions, better use of available space and increased traffic safety.

The main disadvantages of this project are a big investment, the private sector and the authorities not showing the interest in its development and implementation, as well as the fact that several different technologies have been used in its automation, even though the system itself was easy to understand. After several years of development and testing of various concepts, the project was paused in 2002 due to economic reasons (Wiegmans et al., 2010).

4. CONCLUSION

In this paper, an initiative for underground logistic systems has been demonstrated as a solution to the problems of urban environments logistics. The concept combines social benefits by displacing traffic underground and the application of electric propulsion with the advantages of the unobstructed automatic transport through dedicated infrastructure which is separated from the passenger traffic. The idea was to, through various forms of underground transport, present basic characteristics, advantages and disadvantages as well as the results of their application.

The economic advantages of this system include almost direct delivery, 24-hour service, low operating costs and short feedback time. Social benefits include reduction of noise, visual pollution, physical interferences, gas emissions, reducing congestion and traffic jams, more intensive use of available space, relieving the street network and the increase of overall traffic safety. Investment costs are high and technology which is used is new, which leads to lack of experience in automated mass transport systems. The application of these systems requires building the entire infrastructure which means that its realization requires a long period of time.

ACKNOWLEDGMENT

This paper was written on the basis of the seminar work for the subject City logistics. We would like to thank our lecturers, Prof. Slobodan Zečević and Asst. Prof. Snežana Tadić, for sharing their knowledge and expertise generously, and provide genuine encouragement and guidance throughout the project.

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