Supply Chains Digital Transformation: Automated Underground Logistics Systems

Myeongji Shin and Atour Taghipour

***Abstract*—The digitalization is the advent of new technologies, which allows companies to remain competitive. In this context, logistics automation is the application of intelligent artificial or automated machinery to improve the efficiency and effectiveness of logistics operations. These technologies will transform the traditional logistics to digitalized logistics. This paper provides new insights into automated underground logistics systems, based on a literature review and using a few case studies.**

***Index Terms*—Digitalization, automated underground logistics, supply chain.**

I. Introduction

The COVID-19 pandemic calls for a new way of designing and managing the process. Additionally, with continuously increasing volumes of industrial, commercial, and consumer that are globally exchanged, a more efficient logistic system has been being under the requirement ([1], [2]). Moreover, the increasing number of internet-based businesses are stimulating the urge for better logistic chain. There has been a number of suggestions, and one the most innovative methods is building an automated logistic system (ULS) along with a storage underground space ([3], [4]). The freights which were delivered to a harbor or to an airport will be transferred to the distribution hub via an underground rail system which requires no human workforce. Through this way, most ground surfaces that were used for freight railways can be secured. Therefore, considered as an ideal freight system to solve the current problems caused by heavy traffic, it is being examined in some countries such as the US and Japan. Besides, the ULS system is expected to enhance reducing carbon dioxide emission, the amount of micro dust and the noise level. The foremost beneficial factor of ULS is its efficiency in commodity delivery.

In this paper, literature review of academic research will be firstly introduced. And then some drivers of the automated underground logistic system (ULS) will be examined in this paper. Lastly, some practical cases will be taken example.

II. Literature Review

There are some cases examined by several countries with the same concept of the freight system under various names such as Intelligent Transportation Systems (ITS), Underground Freight Transportation (UFT) or Automated Freight System (AFS), etc. Despite these different names, the main ideas all indicate moving and storing freights underground in automatized way. As the traditional logistic system is incapable of dealing with the rapidly growing volume of freights, this innovative logistic system was suggested in order to improve the logistic accuracy as well as to accelerate the speed of the delivery processes. Moreover, the ULS is considered as the best alternative of the freight transport system for the future in terms of reliability, safety, and sustainability when compared with other modes of transports [5].

Developing ULS means to bring advanced technologies in various areas in one place and integrate them. Such technologies to be referred are infrastructure and vehicle technologies, electronics, telecommunications, computing hardware, positioning systems, as well as advanced data processing and sophisticated planning and operation methods. ([6], [7]).

The underground construction for infrastructure should be a precedent for the utilization. The construction work starts from digging the underground tunnel to putting railways and constructing all the facilities necessary. Considering upon the vast physical space where the cargo input starts until its destination, the construction scale would consume long enough time and cost [8]. A number of advanced technologies will be integrated to result in one of the most innovated construction works that can be done today [9].

In a simple manner, ULS functions like metro system that are already in use for many years for human mobility. London metro, which has the longest history with more than 200 years since its first operation, is a symbol of technological solutions to the over populated modern city. Today’s cities are facing the same problem as they were in 200 years ago, yet today’s technologies have been incomparably being improved. It was beforehand for human mobility in the past, but today, the same principle will be applied for freights in an automated way [10]. In other words, the vehicles will be driven by itself to move freight under the human regulation through remote computing system. Only the cargos will be transported and every stop is where the freight storage is. There are two designs that are different from each other despite having the same concept that those designs are all unmanned and therefore working non-stop. The University of Antwerp proposed ULS using conveyer belt to move shipping containers. On the other hand, The Ruhr University of Bochum designed ULS with a use of unmanned electric vehicles on rails that travel through pipelines to deliver cargos [11].

In order to estimate for the ULS cost, life-cycle cost analysis of a short-haul underground freight transportation system for the DFW Airport was referred. The life-cycle of a

Manuscript received May 10, 2021; revised June 22, 2021.
Myeongji Shin and Atour Taghipour are with Normandy University, Le Havre, France (e-mail: atour.taghipour@univ-lehavre.fr, myeongji.shin@univ-lehavre.fr).

doi: 10.18178/joebm.2021.9.2.651

short-haul is an effective engineering technique that is used mostly for an assessment of the financial viability of transportation projects. An article dealing with the case of Fort Worth Airport, which is one of the busiest airports by cargo traffic can be referred for the financial estimation. Although the underground system of short-haul at the airport is different from the ULS, which requires building long tracks in the metropolitan area, some insights can be given. The ULS will certainly require much more facilities and elements. The level of complexity and the scale of construction will be much higher [12].

III. The Drivers of Underground Logistics Systems

Three positive impacts that the ULS might bring is examined in this paper. First of all, it is expected to increase the efficiency of logistic system by improving security, speed of distribution and cost cut in the long term ([13], [14]). Secondly, a less damage to the environment is be expected, while not diminishing logistic performance [15]. Lastly, supersaturated city surfaces can be relieved by ceding some over-ground spaces.

A. Improvement of Logistic Efficiency

The biggest advantage of the ULS is that it increases efficiency in the cargo distribution [16]. Compared to the current distribution system that is involving more human workforce, robotized system is expected to reduce more unexpected events such as hindrances from a weather condition or accidents on roads that could result delays or inaccuracy. Thus, cities will be in better control by preventing massive traffic congestion and this will also enhance the productivity in many domains thanks to more effective supply chain system. This will create a safer logistics environment and increase over-ground the mobility convenience for humans.

B. Environmental Effects

First of all, diminution of different kinds of pollution can be expected as the most part of the system is built underground. The system therefore, is mostly invisible and silent during the operation. Compared other vehicles that are commonly in use today, such as trucks and cargo trains, the ULS's pollution emission is trivial [17]. This will significantly improve a living condition in a metropolitan area. Above all, the diminution of micro-dust pollution and carbon dioxide emission are what are the most anticipated. Yet, its ecological effects can make different results depending on which energy source is used. For instance, if hydrogen energy is used, will be even better for the ecology with the condition that its initial energy source is again clean. At all events, more innovative and experimental energy source can be more easily applied as long as it is less sensitive to safety matters unlike those that are made to carry humans. Delivery drone is often suggested as an alternative for the current delivery transport such as cars or motors. However, regarding its high noise level (about 70dB+ which is the level of louder traffic level in everyday life) and security reason, drone is not yet sufficient for the substitution. Here is the description of delivery drone's process, according to [18]: "systems and devices are provided for securing a drone delivering a package of goods to a delivery destination. A notification may be provided to a device of the purchaser that the drone has arrived near the delivery destination. The drone may hover at a secure altitude from a landing zone at the delivery destination. The drone may receive a purchase code associated with a purchase of the package of goods. The drone may authenticate the purchase code as a condition for landing. The drone may land in the landing zone of the delivery destination when the purchase code is authenticated. The drone may abort the landing when the purchase code is not authenticated. The drone may receive a delivery code associated with completing delivery, the package of goods. The drone may require the delivery code as a condition for releasing the package of goods" [18]. Regarding its complications of the process and the noise level, the drone may more suitable in rural areas rather than the metropolitan area [19].

The concerns with CO_2 emission from transportation, [6] and [7] believe that "the transportation sector is responsible for a significant amount of greenhouse gas emissions: 13% of all emissions of greenhouse gases and 23% of world CO_2 emissions from fossil fuel combustion (ITF, 2008). The last measure stands at 30% in countries of the Organization for Economic Co-operation and Development (ITF, 2008) and was 27% in the United States in 2003 (EPA, 2006). It is estimated that the freight transportation contributes roughly a third of the CO_2 emissions of the world transportation sector (ITF, 2008). This distribution is uneven, however, being worse in large cities, for example. Thus, a report by the Organization for Economic Cooperation and Development (OECD, 2003) assigns 43% of sulphur and 61% of particulate matter emissions in London to freight transportation, while for nitrogen oxides emissions, the figures are 28% for London, 50% for Prague, and 77% for Tokyo. These contributions are growing and are expected to continue to grow with the increase in the freight-transportation activity and the corresponding consumption of fossil fuels. The impact on the freight transportation and logistics sector comes both from the initiatives to control, hopefully reduce, emissions and environmental impacts (e.g., vehicle emission legislation and environmental and congestion road pricing) and from the increases in the cost of energy" ([6] and [7]).

C. A Larger City Space Securement

The current logistic system infrastructure appears insufficient above ground where other vehicles take a huge part of, often making traffic congestion and lack of parking spaces. Every city has numerous functions such as habitation for the citizens, workplaces, preserved green areas and commercial areas. Cities are accordingly densely covered with buildings, parking spaces, different types of roads and small parks. Transferring the logistic system which takes up a huge part of the city's surface into the underground will secure a significant urban area that can be used for other purposes than the current ones. This will create a more agreeable city environment to live in for the citizens [20].

IV. Case Studies

A. Applied Simulation in the Netherlands

The ULS is under discussion in many countries for a better alternative freight transportation of the current logistic system. The case in the Netherlands is reviewed as this country is one of the most optimal country as it deals with high amount of distribution at its port. The relatively small size of the country makes the appliance more practicable. Besides, The Netherlands is aiming to fully replace previous fuel automobiles to electric cars by 2025 in order to attain zero carbon dioxide emission, on the same lines, introducing the ULS is actively discussed. OLS-ASH which is an acronym for Underground Logistic System connecting Alsmeer-Schiphol-Hoofddorp. These three cities are all in the west side of the Netherlands where are near the mainly populated cities such as Amsterdam and Den Haag. Each of these three cities are nominated by their function. Alsmmer, where flower auction requires highly effective cargo distribution system. Schiphol is the city where the international airport and international railway station area. Hoofdoorf, approximate to Schiphol, is the biggest distribution hub in the Netherlands. Having the Port of Rotterdam and the Schiphol International Airport as two important cargo distribution poles, the ULS will be built mostly on the west side of the country in the first hand. And then the system will be built throughout the countries and several poles near the border will enable to send the cargos to the East (Germany) and to the South (Belgium). With the ULS (or OLS-ASH), the Netherlands would expect undisturbed yet more efficient logistic system that could eventually improve the importance as practical trading intersection not only within Europe but around the globe [21].

B. *Toyota's Woven City*

Toyota has released its prototype of a future city planning. Like its name indicates, the city's concept aims for hyper connection and environment-friendly city life. Woven city's four big key words are the connectivity, autonomy, shared mobility and electrification. First of all, the city planning starts with the split of streets into three. The first type of street for electric autonomous vehicles which make zero CO_2 emissions. Trees along the street will be placed. And the second type of street will be for either pedestrians and other types of vehicles than cars such as electric scooters or bicycles. Lastly the third type of street will only be for pedestrians and it be alike to parks. None of these streets are adequate for huge trucks that are in use today in logistics. Hence, the cargos will be mobilized and stored below ground that are in fact connected to buildings. The distribution process is autonomous with the help of robotization. Namely, this is how the ULS will be applied in the future model city. In the buildings were either domestic homes or offices, the new technologies are applied. Accordingly, much part of the daily life will work autonomously by the AI system. For example, a lack of certain ingredients in the fridge will be detected and then be notified on any connected devices and full garbage bins will empty by itself. The Woven City project aims for a sustainable city with minimum carbon footprint. Likewise, All the vehicles in the city will be zero emission by using hydrogen or electric energy source. Aiming to be a standard future city prototype, things and habitants are densely connected to each other, which means the city is highly automatized [22].

V. Resultant Framework for Deployment of Underground Logistics Systems

The following figure shows the 'traditional' delivery process stipulated by Incoterms which is published by the International Chamber of Commerce (ICC). As shown in the schematic image, besides the maritime transport or air transport, the logistic system necessarily requires transportation either by trucks or cargo trains. The ULS will allow these activities to be done underground. In the case of the maritime transport, several ports like the one in Qingdao and Rotterdam are already unmanned. The cargos are moved by AI system and the ULS will connect the automated logistic system to reach the metropolitan area from the port.

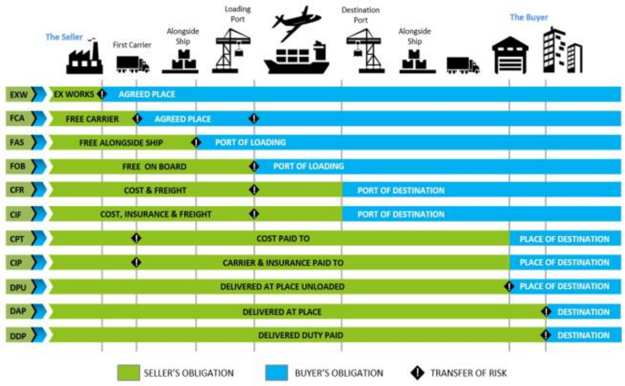

Fig. 1. Incoterms 2020: Point of delivery and transfer of risk. (vivaxpresslogistics.com).

The initial infrastructure construction for the realization of ULS includes railways, tunnels, cargo storage and other facilities. The most innovative part, which is at the same the most challenging part is building the railways with high density under a city, that can be described as a 'huge underground network' made of the railways. This railway system is solely for the freights logistic purpose. Thus, the whole system supposed to be robotized and it should function with the least human involvement except for any special occasions such as unexpected technical problems or regular check-ups. For this reason, the initial infrastructure construction requires a precise examination of the environment where it will be built, as well as the required advanced technologies.

In this context, following are the most basic infrastructure elements required from the initial stage [10]: Tunnel and construction of Tunnel Entry and Exit Ramp, Concert Work for the Invert of the Tunnel; Track; Vehicles; Forklifts; Linear induction motor (LIM).

Let us take an example of a scenario of applying the system in France for better understanding. Counted only three main integral distributions in France: CDG international airport, Port de Marseille and Port du Havre, the infrastructure should be built in those cities where from either the ports and the airport. And then let us suppose that the UFS infrastructure is built underground of the Paris Metropolitan. Firstly, the goods are arriving at the port or the airport in a container and then this container will be shifted by a crane and loaded on cargo train that will go underground. The cargo will be transported to other distribution hub and if required the cargos will be unloaded directly at the warehouse. The connections between the cities will still require deliveries by trucks. When it comes to air transport delivery, the handling comes more in handy at the CDG airport is approximate to the Paris metropolitan. Once the freight lands at the CDG airport in Roissy, the cargo will go underground and delivered to Paris metropolitan area distribution hub. The underground rail in Paris 75 is supposed to be much denser. There will be big distribution poles in each satellite cities surrounding Paris and within the urban area, several metro stations will then have distribution function. For individual clients, the agencies will distribute the goods and for other B2B business clients on-road vehicles will be involved in the delivery to the final destination. If the cargo distribution system could go underground shown above, significant diminution of the congestion is expected.

VI. Conclusion

The digitalization in logistics is consummate with the current trend in every domain. Fuel Cell Electric Vehicle is replacing traditional oil-using cars. Smart Cars that will no longer require driving is expected to be released by 2025. On that score, a previous logistic system that use trucks and trains are now facing a leap. The ULS, an automatized and environed-friendly logistic system is considered as one of the most optimal ways of logistic technology shift.

The industrial Revolution made exploit fossil power and then until now the predominant energy source depended on oil. However, due to the rapidly rising environmental issues, energy source diversification is being actively researched. Now the global aim is not simply reducing the carbon by 15% or 20%, but to 0. Regarding this global agent that is getting more urgent, ULS can be a very good opportunity to many industries and countries. It would enable industries to keep developing in respecting the environmental regulations agreed internationally.

The initial construction cost is not negligible for the reason why it has to be built underground and requires high technology with numerous examinations. Nonetheless, once the infrastructure has been built, the fixed cost is expected to diminish afterwards. Although the most distinctive of ULS is its functionality underground, however, some part can be built above ground as the construction is less costly ([23], [24]).

The ULS perfectly comply with Industry 4.0 that has already been taking part of our everyday life.

The biggest features of Industry 4.0 are: smart mobility, smart logistics, smart products, smart building, smart grids and smart factory. The ULS will be an efficient grid that will connect those elements in the near future, just like what Woven City designs for a future city prototype.

In Qingdao, China presented its newly innovated port in 2019. This high-tech port combined with 5G enables to control six cranes by one person and the time it takes to put down a cargo is less than 90 seconds. It has reported the efficiency of work at the port increased up to 30% than the previous port system. This new port has now replaced its energy source from diesel oil to hydrogen energy which resulted in a remarkable diminution of carbon dioxide and sulfur dioxide. An example which is showing the actual change in the logistics systems combining new technology, introduction of the Automated Underground Logistic System examination seems exigent in order to result in further improvement of logistic system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Myeongji Shin conducted the research; Atour Taghipour supervised the research, Myeongji Shin and Atour Taghipour wrote the paper; all authors had approved the final version.

References

[1] M. Merimi and A. Taghipour, “Accelerating the digitalization of the supply chain: An empirical research about COVID-19 crisis,” in *Digitalization of Decentralized Supply Chains During Global Crises*, IGI Global, 2021, pp. 1-24.

[2] A. Taghipour, S. Murat, and P. Huang, “E-supply chain management: A review,” *International Journal of e-Education, e-Business, e-Management and e-Learning*, vol. 11, no. 2, pp. 51-61, 2021.

[3] J. G. Visser, “The development of underground freight transport: An overview,” *Tunneling and Underground Space Technology*, vol. 80, pp. 123-127, 2018.

[4] J. C. Rijsenbrij, B. A. Pielage, and J. G. Visser, “State-of-the-art on automated (underground) freight transport systems for the EU-TREND project,” Thesis, Delft University of Technology, 2006.

[5] S. Shahooei, S. P. Mattingly, M. Shahandashti, and S. Ardekani, “Propulsion system design and energy optimization for autonomous underground freight transportation systems,” *Tunneling and Underground Space Technology*, vol. 89, pp. 125-132, 2019.

[6] T. G. Crainic, M. Gendreau, and J. Y. Potvin, “Intelligent freight-transportation systems: Assessment and the contribution of operations research,” *Transportation Research Part C: Emerging Technologies*, vol. 17, no. 6, pp. 541-557, 2009.

[7] T. G. Crainic, N. Ricciardi, and G. Storchi, “Models for evaluating and planning city logistics systems,” *Transportation Science*, vol. 43, no. 4, pp. 432-454, 2009.

[8] A. Taghipour, P. Hoang, and X. Cao, “Just in time/lean purchasing approach: An investigation for research and applications,” *Journal of Advanced Management Science*, vol. 8, no. 2, 2020.

[9] S. Shin, H. S. Roh, and S. H. Hur, “Technical trends related to intermodal automated freight transport systems (AFTS),” *The Asian Journal of Shipping and Logistics*, vol. 34, no. 2, pp. 161-169, 2018.

[10] S. Shahooei, M. Najafi, and S. Ardekani, “Design and operation of autonomous underground freight transportation systems,” *Journal of Pipeline Systems Engineering and Practice*, vol. 10, no. 4, p. 05019003, 2019.

[11] C. Delmastro, E. Lavagno, and L. Schranz, “Underground urbanism: Master plans and sectorial plans,” *Tunneling and Underground Space Technology*, vol. 55, pp. 103-111, 2016.

[12] S. E. Zahed, S. M. Shahandashti, and M. Najafi, “Lifecycle benefit-cost analysis of underground freight transportation systems,” *Journal of Pipeline Systems Engineering and Practice*, vol. 9, no. 2, p. 04018003, 2019.

[13] H. Radhoui, A. Taghipour, and B. Canel-Depitre, “The distribution and pickup of goods: A literature review and survey,” *Hierarchical Planning and Information Sharing Techniques in Supply Chain Management*, pp. 46-85, 2019.

[14] Y. Tliche, A. Taghipour, and B. Canel-Depitre, “Exploring a downstream demand inference strategy in a decentralized two-level supply chain,” in *Demand Forecasting and Order Planning in Supply Chains and Humanitarian Logistics*, IGI Global, 2021, pp. 1-65.

[15] A. Taghipour and C. Beneteau-Piet, “Sustainable supply chain management performance,” *International Journal of Innovation, Management and Technology*, vol. 11, no. 6, 2020.

[16] R. Ooishi and E. Taniguchi, “Effects and profitability of constructing the new underground freight transport system,” in *Proc. International Conference on City Logistics*, 1999.

[17] A. Tabesh, M. Najafi, T. Ashoori, R. Tavakoli, and S. Shahandashti, “Environmental impacts of pipeline construction for underground freight transportation,” *Pipelines*, pp. 181-191, 2017.

[18] S. Ganesh and J. R. Menendez, U. S. Patent No. 9,359,074, Washington, DC: U.S. Patent and Trademark Office, 2016.

[19] H. Radhoui, A. Taghipour, and B. Canel-Depitre, “Mixed delivery and pickup vehicle routing problem with limited flow and assignment of drones in an urban network,” in *Demand Forecasting and Order Planning in Supply Chains and Humanitarian Logistics*, IGI Global, 2021, pp. 225-249.

[20] W. Wisetjindawat, "Review of good practices in urban freight transportation," *Sustainable Urban Freight Transport*, vol. 80, pp. 44-60, 2010.

[21] B. J. Pielage, "Underground freight transportation. A new development for automated freight transportation systems in the Netherlands," in *Proc. 2001 IEEE Intelligent Transportation Systems*, August 2001, pp. 762-767.

[22] J. Alves, "Toyota to build prototype city of the future," *Links*, vol. 2960, no. 2015, pp. 656, 2016.

[23] M. Najafi, S. Ardekani, and S. M. Shahandashti, "Integrating underground freight transportation into existing intermodal systems," Report No. 0-6870-1, 2016.

[24] A. Taghipour, "Improving the plan of a manufacturing network with non-integrated business units," *International Journal of Applied Logistics*, vol. 5, no. 2, pp. 1-11, 2014.

A. Taghipour is a professor and the head of two international management master programs at Normandy University in France (master of international purchasing and master of international marketing). He holds an HDR in management from Normandy University and a PhD in industrial engineering from the Polytechnic School of Montreal in Canada. He received two masters' degrees, one in management, logistics & strategy and other in industrial engineering. He has more than ten years of experiences as a manager in automobile industries. He has published different books and many research papers in international journals. His areas of research are supply chain and operations management.

M. Shin is an international master candidate at Normandy University in France. She holds bachelor degrees from Myongji University in South Korea, at Cergy-Pontoise University in France and Chinese Culture University in China. Her areas of research are purchasing, supply chain and operations management.