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The development of underground freight transport: An overview

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ABSTRACT

Today, transportation of freight by trucks and vans faces congestion within most of the urbanized areas around the world, making supply chains less efficient and causing air pollution, noise, reducing traffic safety and also contributing to climate change. Underground freight transport (UFT) can be an alternative for, but also an addition to existing transport modes for freight, like road, rail and waterborne. It combines the advantages of taking the traffic movements underground and applying electrical (or linear induction) propulsion, with a lower (local) environmental burden and the economic advantages of unimpeded automated transport over a dedicated infrastructure that is separated from passenger traffic. Through the years, initiatives haven been taken to develop underground freight transport systems for different purposes in the USA, Europe and Asia. This paper describes the different initiatives, the benefits and costs and the type of applications. The paper ends with the conclusion that UFT is ready to be implemented but there are points of attention. We are dealing with a process of prolonged efforts on the part of the government and the private sector, which requires long-term commitment and high financial resources.

1. Introduction

Today, throughout the world, large volumes of chemical and petrochemical products are transported between ports and industrial complexes in pipelines. This occurs mostly underground which is safe, reliable, cost effective and with minimum environmental impact and also as energy-efficient as possible. And nearly every domestic and business property in cities is connected by pipelines for drinking water and sewage. It is unthinkable that these goods would be transported by any other means. According to the OECD (2017), the global freight demand grows with about 3 percent every year. This means that the demand for freight transport will almost double between 2015 and 2030 and triple between 2015 and 2050. In Asia, inland freight transportation (by road, rail and waterborne), measured in tonne-kilometers will increase by a factor of 3.2 from 2015 to 2050 accounting for over two-thirds of all inland freight globally. Measured in vehicle-kilometers, almost half of the freight transportation will take place in urban areas and is related to urban delivery. Most of the inland transportation of freight takes place by trucks and vans, facing congestion within most of the urbanized areas around the world, making supply chains less efficient and causing air pollution, noise, reducing traffic safety but also contributing to climate change. Electrifying trucks and vans can help to reduce emissions and automated driving can reduce costs but do not reduce congestion and the use of urban space.

Maybe it is time to look as a society at other transport solutions. One of the solutions, which is proposed and investigated, is underground freight transport. Underground freight transport (UFT) can become an alternative for but also an addition to existing transport modes like road, rail and waterborne. Underground freight transport combines the advantages of taking the traffic movements underground and applying electrical (or linear induction) propulsion, with the economic advantages of unimpeded automated transport over a dedicated infrastructure that is separated from passenger traffic. The past twenty five years, there have been studies to the opportunities and the social added value of underground freight transport (UFT-) systems, in which goods are transported invisible for the public and undisturbed by weather and other traffic. These studies (see Rijsenbrij et al, 2006) show that there are possibilities for underground freight transport, like transport of coal, palletized goods and containers and that there are environmental benefits, energy efficiency and transport benefits.

The purpose of this article is to discuss the progress of underground freight transportation by capsule pipelines and other tunnel systems. Although the term underground is used, it can also refer to pipelines or tubes or other enclosed infrastructure lying above-ground, as long as the transport takes place unmanned and automated.

The information in this paper is based on material that was presented at the different editions of the International Symposium Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems (ISUFT). This paper only contains a part of the information that is available in the proceedings and other reports. In the near future ISUFT hopes to build an extensive digital library on this topic on the ISUFT website (www. ISUFT.org).

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2. A little history of pneumatic capsule pipelines and underground freight transport

Underground freight transport can take place in the form of capsule pipeline transport when it concerns smaller objects (less than 1 m diameter) and for larger objects in the form of individual vehicles or trains through tunnels. The first built pipeline transport systems were pneumatic dispatch systems (USDOT and Volpe, 1994) for moving telegrams and messages from telegraph centers to other offices as part of the telegraph system. The first system came in operation in 1853 and connected the offices of Electric and International Telegraph Co. with the London Stock Exchange. By 1909 London had 40 miles of tubes, and 17 British cities also had this type of service. Such systems became operational in the rest of Europe as well as the rest of the world: Berlin (1865), Paris (1867), Vienna, Prague, Munich, Hamburg, Rio de Janeiro, Dublin, Rome, Naples, Milan and Marseille, and in the USA: New York City, Boston, Philadelphia, St. Louis and Chicago (Standage, 1998). Due to the rise of modern telecommunications technology, these systems lost their importance. In buildings such as offices, banks and hospitals one can still find these systems occasionally (Visser, 2002).

Also larger capsules were used. From 1859, the London Pneumatic Dispatch used wheeled PCPs, weighing up to 3 tons in a tube (76 × 85 cm) on a 61 cm gauge track on different lines. In 1874, the London Post office no longer saw prospect of using the system and the system was shut. In the 1960s, renewed interest in larger diameter pneumatic capsule pipelines led to the development of wheeled PCPs. In 1971 at Stocksbridge, Georgia and 1973 at Houston two prototypes were constructed, the first with a pipeline diameter of 0.91 m and the second with a diameter of 0.45 m. Both systems became known as 'Tubexpress'. Also, in the UK and Russia, wheeled PCP systems were developed. Several Russian 'Transprogress' systems were built and commercially used between 1971 and 1983. The first system was designed for the movement of crushed rock. It was used in Tibilisi, Georgia. Other systems were applied for the movement of gravel, sand, minerals, and even waste (St Petersburg). The Soviets had plans for 20 or more systems across the former USSR. Although no new plans have since been developed, the Russian company still exists. Japan has successfully used PCPs of one meter diameter in permanent installations (for transporting limestone to a cement plant), as well as in temporary construction projects (for transporting earth and construction materials in large tunneling and highway projects). In 1994, Japanese researchers at Kawasaki and NKK tested a prototype for a capsule transport system that was powered by linear synchronic motors (LSM). The test run was on a trajectory of 45 m with a tube 30 cm in diameter. Also in the USA, tests took place. A demonstration project (Montgomery et al., 2000) which uses a linear synchronous motor to move capsules was constructed at IMC-Agrico, a phosphate mining company in Lakeland, Florida, USA.

At the beginning of the twentieth century, another type of freight transport system was developed. In Chicago, an underground rail transport system for waste and coal was operational from the beginning of the century until 1959 (see Moffat, 1982). In London, an underground transport system, called Mail Rail, came into operation in 1927 and has been used for almost 80 years for the transport of mail between post offices within Central London (see Bliss, 2000). Mail Rail stopped to operate in 2006. From July 17th 2017 Mail Rail has been reopened as part of the Postal Museum in London. In the 1970s ideas were developed in Europe, Japan and the USA for high-speed transport systems for passengers and freight. Besides the advantage of transport at high speed and over long distances, these systems also benefit from relatively low energy-use and limited nuisance to the environment when they are operated underground in low-pressure tunnels. Eventually, these systems were never built, but lately, due to Elon Musḱs hyperloop initiative, there has been a renewed interest in high speed freight and passenger transport with capsules (Dalagan, 2017).

In the 1990s, a strong interest for underground freight transport grew in the Netherlands, Japan, the USA and the UK. In Japan, an investigation (see Taniguchi et al., 2000) was carried out into establishing a dedicated underground infrastructure for freight transport by light trucks that ride through tunnels (Dual Mode Truck). This project and the L-net Tokyo project, a metro-like system for mail-transport underground within Tokyo, were discontinued in 1994. In the USA, a capsule transport system, called Subtrans was developed (see Vandersteel, 1992) for the use of transporting mail and parcels between distribution centers of UPS, TNT and EMS and Newark Airport near New York. In the UK, a feasibility study was conducted to determine if the underground connections between post offices in Central London used by Mail Rail can be used for the distribution of freight and mail with Metrofreight, a new automated transport system (see Clarke and Wright, 1993). In the Netherlands, between 1994 and 2001 different research programs researched the technical and financial feasibility of Underground Logistics Systems (ULS) in urban areas, but also the use of ULS at airports, seaports and industrial areas (Rietveld et al., 1999). At Delft University of Technology, a test site was in operation until 2001. In Germany the Ruhr-University Bochum (see Stein and Schoesser, 2000) conducted research on CargoCap. A 1:2 scale model of Cargo Cap was developed to test the main components of the capsule. The feasibility of a long-distance freight pipeline system was investigated by the Texas Transportation Institute's Rail Research Center (Roop and Bierling, 2000).

In the year of 2013, Mole Solutions developed a freight pipeline demonstrator, located at the Alconbury Weald Enterprise Park, near Cambridge, UK (Silverthorne and Zhou, 2016). The Phase I demonstrator track comprises the basic elements of a curve, a straight section and a switch, and provide a track length of 105 m. The demonstrator utilizes two capsules to transport bulk material between the ends of the track. Mole Solutions developed a freight pipeline system for transport aggregates and a system for moving pallets in the retail sector. They did a feasibility study for the city of Northampton, UK. Mole Solutions are now moving forward to the next phase to have a full circle test track to test a fully operational freight pipeline system. CUIRE from the University of Texas in Arlington investigated the feasibility of freight capsule systems between cities, at airports and for long distance freight traffic. This multi-year research program showed that there are options for the future. Cargo Sous Terrain (CST) in Switzerland and the JTC Underground Inter-Estate Goods Move system in Singapore focus on actually building an underground freight system, both in areas in which no or difficult transport solutions can be found above ground. China has investigated freight capsule pipelines since 2003, for instance for moving containers to and from the ports of Shanghai (Fan et al., 2016) and for collecting waste in Shanghai (Yu and Fan, 2010). From 2005 multiple research projects have been presented at ISUFT symposia (see www. ISUFT.org). Freight traffic in cities and at seaports in China is increasing rapidly and is generating congestion problems and environmental issues. Freight capsule pipelines are considered to be a solution.

3. Benefits and costs

Underground freight transport combines the advantages of taking traffic movements underground, in this way reducing the use of space and applying electrical (or linear induction) propulsion, with the economic advantages of unimpeded automated transport over a dedicated infrastructure that is separated from passenger traffic. The economic advantages are to be found in an almost direct delivery, twenty-four hour service, relatively low variable and exploitation costs and short turn-around times. Other advantages concern the lower (local) environmental burden, resulting in reduction of noise, visual pollution and emissions, reduction of congestion problems, reduction of energy use, and a related reduction in CO_2 emissions, more intense use of available space and an increase in traffic safety. According to Braet (2011) underground freight transport of maritime containers to the

Table 1
Categorization of systems to type of cargo and distance (Rijsenbrij et al., 2006).

Load unit Distance	Parcel/box size	Pallet size	Container/Swap body size
Short distances (up to few km)	Roller Conveyor Belt Conveyor AGV's Tube systems	Roller conveyor Belt Conveyor AGV's	AGV's
Medium distance (several tens of km)	Tube systems	AGV's Automated truck (DualModeTruck) Capsule systems	AGV's Automated Trucks /MTS Automated Trains
Long distance (several hundreds of km)		Capsule systems	Automated Trucks/MTS Automated trains Large capsule systems

hinterland has less than half of the environmental impact of road transportation.

On the other hand, a completely new underground infrastructure must be provided. This requires high investments, a long realization time, and much fine-tuning with (local) stakeholders.

4. Applications

Underground freight transport can have an important function as an alternative for road transport, for instance in the combined development of inter-modal freight transport by rail or inland navigation and in urban freight transport. The following applications of underground freight transport can be found in the studies described earlier (Visser, 2002):

1. In urban areas, for provisioning post offices, retail trade, catering establishments, office, and consumers. This application concerns the transport of load-units of pallet size. The feasibility of this application has been researched in Dutch cities, Japan (Tokyo), China and in the UK (London).
2. Inside or between industrial complexes, logistical centres, and multimodal terminals, such as airport and harbor complexes. This application concerns the transport of load-units such as pallets, maritime containers and aircraft pallets. ULS Schiphol in the Netherlands (IPOT, 2000) UCM (Winkelmans and Van Wassenhove, 2010) for the port of Antwerp, UCFT (Fan et al., 2016) Shanghai and the JTC Underground Inter-estate Goods Mover System in Singapore are examples of this application.
3. Collection or long distance transport, such like agricultural products, ore and solid waste. For this purpose, capsule pipelines have been developed and applied in Japan, the USA, and Russia. Cargo Sous Terrain (CST) from Swiss is a long distance transport system for piece goods.
4. Hinterland or cross-country transportation of maritime containers. Studies have been done in the USA, Belgium and Germany.

The feasibility of different applications for the city of New York can be found in Liu (2004). Also the size of the pipelines or tunnels differ. Based on the studies in the Netherlands (Binsbergen and Visser, 2001) the following types and diameters of underground freight transport systems can be distinguished:

- Colli systems, consisting of a small tube with a diameter of approximately 1.5 m, used for the transport of small load units of 0.60 (l) × 0.40 (w) × 0.60 (h) m, named “Colli”. This system is suitable for the transport of boxes and parcels.
- Pallet systems with a medium tube with a diameter of between 2 and 3 m, used for the transport of pallets of up to 1.25 (l) × 1.25 (w) × 1.80 (h) m. This system is suitable for the transport of pallets, roll-containers, and pallet-boxes.
- Container size system with a large tube with a diameter of about 5 m and more, used for transportation of large units such as containers.

It is also possible to make combinations, e.g. a citybox system as a trunk line and a pallet system or container system for further distribution of loads.

The Colli system has the advantage of a small tube diameter, so that the tubes are cheaper to put in place and a network with a finer mesh can be established. In addition, it is possible to set up a semi-continuous transport system with very short reaction times. It would be, in other words, a courier service for consumer goods. On the other hand, it must be noted that if only part of the goods can physically go through these tubes, that the logistics have to be adapted, that the tube is not directly accessible for repairs, and that the capacity is limited. In comparison, the Container size system is actually capable of having small trucks drive through the tubes. The advantage is that it has a large capacity and that transhipment is not necessary. On the other hand, the construction costs are much higher, while only a few connections can be realised. The Pallet system is a good compromise: it has a decent capacity with relatively low construction costs, while the logistics hardly needs any adaptations. The UFT system, when a Pallet system is used, can utilize existing load units, such as roll-containers and pallets with a maximum footprint of about 125 by 125 cm. It is, in principle, possible to go to a maximum height of 185 cm; however, we assume a maximum height of 150 cm. It is likely that the introduction of a new underground freight transport system will lead to new standards. It is essential that no (or as few as possible) extra actions need to be performed in order to get the load unit into the system since extra actions create loss of time and increase of cost.

The different systems can be categorized as presented in Table 1. Horizontally three different type of load units are presented increasing in size from left to right. Vertically the typical travel distance is presented, starting at the top with short distance and increasing downwards. Although in theory all systems could be used (or adapted) to transport all types of cargo over different distances, this categorization presents the systems where they are most likely / practical to be implemented.

5. Ready to implement?

The implementation of underground freight transport requires special attention. The technology is not critical to the development of underground freight transport systems anymore, since the required technology is already available. More critical is the right market implementation. Compared to the situation twenty years ago, the field of logistics is changing in favor of UFT due to consolidation within the transport market, new logistics management concepts focusing on multimodal consolidated supply chains and new ideas such as the Physical Internet (Montreuil, 2012).

Conditions must be right, like sufficient goods to transport and also favorable conditions underground. Since the underground is more and more used for different purposes, it gets more and more difficult to find alignments for tunnels or tubes. The feasibility studies of ULS in cities in the Netherlands for the Dutch government (IPOT, 2000) showed that underground space was available but only at deeper levels (more than 10 m deep).

With a growing global population and increasing urbanization worldwide the use of the underground becomes evident. More and more facilities are planned underground in cities like Hong Kong, Singapore and major Chinese cities. Also in cities in Europe and the USA, the underground is already used up by shallow underground utilities (including water, wastewater, natural gas, electrical, cable, telecommunications) and deeper underground road tunnels, metro lines and sublevel shopping facilities.

6. Discussion and conclusions

For more than a century people have used underground transportation within metropolitan cities, so why not put freight underground? The expectation is that underground freight transport systems can lead to a socially attractive transport system, as well as to a considerable improvement in the performance of goods transportation. Research into these systems supports these expectations. New freight transport concepts generate large economic and social benefits but need large investments.

Vance and Mills (1994) say the following about the implementation of 'tube freight transportation': "It is evident that a comprehensive tube freight system cannot be financially and physically implemented overnight even if this were a national objective. Several transitional approaches can be envisioned. The first option is to build the most needed and financially viable segments in congested areas. This approach has the obvious disadvantage of requiring standardization after initial segments are built and operating. A second approach is to develop a national plan with appropriate standards established in advance. This was the general approach taken to implement the interstate highway system. This approach would appear more appropriate for the introduction of tube freight transportation in congested areas. However, it has the disadvantage of requiring an extensive period of planning, consensus-building, and enactment. A third approach is to assume tube freight transportation would only provide niche, general commodity services and allow totally private planning and development with limited enabling legislation and, perhaps, access to federal rights-of-way".

Whether it is developed as a niche or as a national plan, we are dealing with a development path of prolonged efforts on the part of the government and or the private sector. It is therefore not easy to come to a definitive decision regarding the position of underground freight transport in future goods transport management.

Research will be necessary to increase our knowledge of underground freight transport, and thereby reduce the existing uncertainties. Not only technical and logistical knowledge is needed, but also knowledge about social and administrative aspects. The key questions that have been addressed in earlier studies, as mentioned in chapter 2, are still valid: What supply chain markets are applicable? What is the nature and size of the economic, social and environmental benefits? What is the optimum specification for an underground freight transport system? What is the optimum blend of proven technologies? What is the optimum development route? How should the development be funded? Which legal and governance issues must be addressed?

Private funding is becoming an option since private investors are getting more interested in funding infrastructure as the cases of Cargo Sous Terrain in Switzerland and Hyperloop in the USA show.

Due to the public character of the UFT, the government, however, will have a responsibility with respect to the decision making, developing proper 3D planning of activities underground to make long alignments of tunnels possible and may even be in charge of the construction and operation of the infrastructure. Even if the UFT infrastructure will be developed by a limited number of parties and will be exploited on their "own" property (it is then private, and not public), the role of the government is required. The importance of a proper regulatory framework to manage property rights and the governing of underground use and developments are essential, even when it concerns private properties. An efficient use of the underground requires also an integrated planning approach, for the surface and subsurface combined, for the longer term perspective but also for the shorter term.

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Appendix A. Supplementary material

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