



Are freight pipelines a pipe dream? A critical review of the UK and European perspective

Obiajulu N. Egbunike*, Andrew T. Potter¹

Innovative Manufacturing Research Centre, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, CF10 3EU Wales, United Kingdom

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ABSTRACT

Freight pipelines represent a novel way for the movement of freight transport and offer an alternative to conventional transport modes. The aim of this paper is to examine the potential for this transport mode within the UK and Europe. Firstly, the latest technological developments are identified, building on the last major review by Howgego and Roe (1998). There is then an analysis of the policy landscape towards freight pipelines, as successful implementation will require the support of policy makers. Finally, some of the major benefits and issues with freight pipelines are highlighted. We conclude that there are still opportunities for the use of freight pipelines, but that further research is yet required to fully understand the supply chain, logistics and other related activities that the introduction of this technology may influence. This is because systems which are presently in commercial operation have exhibited excellent characteristics, although they have not been more widely adopted.

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1. Introduction

There has been a desire amongst policy makers to reduce the wider impact of freight transport by encouraging sustainable distribution (for example, see DETR, 1999; European Commission, 2001; Department for Transport, 1999). A major objective is to reduce the environmental impact of freight transport, while not compromising the economic sustainability of the freight transport sector. Many initiatives relate to improving the use of the current network infrastructure that is available. However, some stakeholders have also argued that there is a need for new ideas and innovative means of transport to further meet the sustainability objectives.

One such approach to this could be through the transfer of solids through large diameter freight pipelines. ASCE Task Committee (1999) defines freight pipelines as “all pipelines that transport freight – solids, bottled liquid, or bottled gas”, and state that three types exist – pneumatic, slurry and capsule. The first two of these do not require the product to be contained and are often used for bulk/commodity products. Capsule pipelines transport freight in capsules propelled by a fluid moving through a pipeline. When the fluid is air or another gas, the technology is called pneumatic

capsule pipeline (PCP), and, when water or another liquid is used, it is termed hydraulic capsule pipeline (HCP) (ASCE Task Committee, 1999). More recently, electrically powered systems have been developed (such as CargoCap and Pipe&net), due to certain limitations shown to exist when using the PCPs and HCPs. While they may not be considered capsule pipelines, they do fit within the broader definition of freight pipelines, given the definition by Howgego and Roe (1998) as “a sealed dedicated transport way through which any product may be propelled”.

With these new innovations however, full industrial applications remain limited. This continually brings to the fore the question by Winkelmanns and Notteboom (2000) asking whether the current situation with respect to traffic and transport in developed countries can be improved substantially by integrating pipeline transport as a consistent and equal transport mode.

The aim of this paper is to examine the likelihood of the adoption of this innovative transport mode as an alternative to the more traditional transport approaches. In order to gain an in depth understanding, we focus on the UK and consider both the technology and policy context. For comparison purposes, we also look at other countries within the EU to ascertain their technological and policy levels of acceptance to this concept.

While some interest has been shown in the UK over the past 30 years (for example, Butler, 1978; Baker and Hawrych, 1982; Clarke, 1993; Howgego and Roe, 1998) no large scale schemes have been formally developed. However, a report on the views of UK logistics professionals under 35 identified potential opportunities for this mode in the future (Beecroft et al., 2003). In order to

* Corresponding author. Tel.: +44 (0) 29 2087 9617; fax: +44 (0) 29 2087 9633.
E-mail addresses: egbunikeo@cardiff.ac.uk (O.N. Egbunike), potterat@cardiff.ac.uk (A.T. Potter).

¹ Tel.: +44 (0) 29 2087 5214; fax: +44 (0) 29 2087 4301.

generalise the results, the position of the UK relative to other European nations is considered.

In terms of contribution, the last significant reviews of research in this field were *ASCE Task Committee (1999)* and *Howgego and Roe (1998)*. The focus of the former was majorly on the technological state of the art as well as the expected use of various types of freight pipelines. The latter dealt with the application of this concept within urban distribution networks. With both reviews carried out during the late 1990s, there is a need to evaluate technological developments since then. While there is no shortage of studies in the international arena, there are a few UK/European focused studies. Equally, much of the published research focuses upon the pipeline technology, with little consideration to the policy aspects. In conclusion, although this paper focuses upon freight pipelines, we shall also consider transport policy references towards innovative transport modes in general. This is because a healthy policy interest, support and promotion of transport innovations will facilitate the nurturing of the freight pipeline concept.

To address the objectives of this research we undertake a synthesis of the available literature relating to the concept of underground freight transportation with particular emphasis on freight pipelines. We also examine the policy environment within the UK and Europe. Consideration was given to policy both at a national and regional level. At a regional level, the latest transport policy documents were examined to identify attitudes towards pipelines, capsule pipelines and innovation within transport. Innovation was included as policy makers may not wish to commit to a particular technological development but do wish to encourage innovation, either within the current transport network or in developing new transport modes. Finally, a review of European policy was carried out, considering policy documents produced by the EU and also national governments within Europe. The objective was to find recent policy documents, rather than looking historically, to provide some breadth in generalising the results. For all of the above stages, the information gathered is correct as to the end of 2008.

2. The history of capsule pipelines in the UK

George Medhurst in 1810 while experimenting with compressed air, proposed the use of air for conveying letters and goods and in addition published other proposals for human transport in 1812 and 1827 (*Howgego, 2000*). Further citations (*Self, 2004* and *Brennan, 2005*) attribute the invention and initiation of commercial pneumatic systems carrying capsules to Medhurst.

The first practical implementation was however built by Latimer Clark who, with the need for almost 'real time' information for traders installed a 220 yard long pneumatic tube connecting the London Stock Exchange with the Central Station of the Electric Telegraph Company (*Hayhurst, 1974*). Following this success, Clark teamed up with T.W. Rammell to patent a pneumatic railway, in which carriages were placed inside a larger diameter tunnel or tube. This was put into service in 1863, with the post office being the prime customer (*Brennan, 2005*). According to *Trench and Hillman (1996)* this pneumatic railway ran from the District Post Office in Eversholt Street to Euston Station. Compressed air pushed the carriages from behind while an air vacuum pulled from the front.

In 1864, a similar system to Clark's 1853 system was duplicated. This time, C.A. Varley implemented a 300 yard system in Liverpool between the Electric Telegraph Company office and another office in Walter Street. This however, was the first system with capsules being sent in both directions using the same tube (*Howgego, 2000*).

These early developments were then exported to the rest of the world, with similar installations following in Berlin (1865), Paris

(1866) and Prague (1889). The Paris pneumatic postal system had a diameter of about 3 in. and was used for small packets, which were transported around an extensive network of tens of kilometres (*Hodson, 2007*). This technology reached New York in 1876, where a 6-in. diameter 3000 foot long system was constructed.

While a lot of these infrastructures still exist, they are not actively in use today. The Paris network was used until 1984 and then abandoned due to the growing use of modern telecommunication systems for communication including computers, phones and fax machines. The system in Prague was in use until 2002, when a flood affected five out of the eleven underground machine rooms. The system is however under repairs and is to be preserved as part of the country's national heritage (*Telefonica, 2008*).

Currently, very similar systems are still being utilized in large retail and grocery stores, where cashiers send money enclosed in capsules, through internal tubes to secure, centralized collection points somewhere else within the building. Similar systems are used in hospitals, where drugs and other items are sent to particular collection points after the prescriptions have been sent via the same medium. However, over the years, the interest in this technology has heightened for transporting larger volumes of goods. Once again, various research projects were targeted at the technology behind this system and ways in which this technology could be integrated into the transport sector, for example, building the system for palletised goods. These required larger diameter tubes than previously seen, and form the focus for the rest of this paper.

3. Freight pipeline technology development

3.1. UK

The UK has experienced numerous operational systems as well as a number of other research activities revolving around this concept since Latimer Clark carried out the first freight pipeline test in London the 1860s. The focus of this paper however is to review the status of this concept post 1900 with a focus on larger diameter pipes.

In terms of a real-life and to scale freight pipeline in the UK, the Mail Rail system of London, which commenced operations in 1928, is an appropriate exemplar of this concept. Although its features are far removed from the defined concept, a study of this system can give insights to the benefits of an operational freight pipeline concept. This fully automated, computer controlled underground train system supported nine stations and transported between four and 12 million postal items across London daily. Having been designed solely for the movement of letters and parcels, it was mothballed in 2003 after operating for over 75 years.

In terms of research activities directly related to capsule pipelines, the main examples are:

- The BHRA² and TRRL³ test facility. An initial interest in capsule pipelines came during the 1970s through the BHRA and TRRL. This research program included the installation of a full scale test facility at Milton Keynes, which culminated in a patent developed from small laboratory models through the successful full-scale field trials in 1977 (*Baker and Hawrych, 1982*). Owing to this early nature of the BHRA project, the concept of using blowers as a means to propel the capsules was still novel and must have been considered a high level of development then. This is supported by the implementation of the Sumitomo capsule pipeline system in Japan in 1982 which was then considered a novel

² British Hydromechanics Research Association.

³ Transport and Road Research Laboratory.

concept in transportation. Today, this system is still in commercial operation and still uses the blowers as its means of propulsion. These two systems, BHRA test system and Sumitomo capsule systems, exhibit a closer relationship to the definition of 'capsule pipeline' systems as the goods being transported are enclosed in capsule-like cases and forced through the pipeline by fluids, such as compressed air.

- *Metrofreight*. Clarke (1993) researched into a system for automated freight transport to take advantage of advancing technology in order to reduce the adverse impact of freight transport on the environment. He sought to positively impact upon the operational performance of the transport system as a whole hence, an included objective of this research project was the simulation of this system for efficiency improvement. While there was no specific mention of pipelines or any form of underground or subterranean networks, the general concepts of automated transportation systems remained the same, bearing a great similarity with those of freight pipelines. Furthermore, Clarke (1993) specifically mentioned, "the use of dedicated road infrastructure" for the Metrofreight system, implying the need for further 'above ground' infrastructure development – the downside of which meant the continuous conflict for a gradually depleting resource, space. However, with later reports showing a collaborative study with a consortium including John Lewis, the Royal Mail and Selfridges (Pepinster, 1997; Basset, 2001), the target was the re-use of the former Mail Rail infrastructure. The goal was to upgrade the system to commence the delivery of goods to Oxford Street via the underground tunnels, thereby reducing traffic and congestion on the roads above. With this final development, the Metrofreight study on the automation of freight transportation could be referred to as a freight pipeline rather than a capsule pipeline.
- *Foodtubes*. Hodson (2007) proposed that in the future, food should be transported via dedicated pipelines, under the brand name Foodtubes. He proposes that a ring of over 1500 km might initially encircle the UK, "linking loops that connect to all major food producers and retailers, making approximately 3000 km of pipe". While Hodson presents some initial calculations, the idea can be considered to be at an early conceptual stage of development currently.

With the interest shown in specific technologies and the possibilities they present, some more general studies were carried out to evaluate the costs associated with sending goods enclosed in capsules through pipelines as well as the proposed uses for these pipelines. Butler (1978) based his study on initial results from the BHRA/TRRL pneumatic capsule test loop at Milton Keynes. Further reference was made to the study carried out in the United States by Zandi and Gimm (1976), who carried out a comparison of freighting cost by different methods and concluded that the economics of the systems depend on the volume of freight, distance moved and shipment size. Butler (1978) showed that steel pipelines accounted for 30–50% of the total discounted cost of a pneumatic pipeline project and a much higher proportion of the initial capital cost.

In a separate exploratory study, James (1980), collaborating with the Department of the Environment, the Department of Transport as well as the TRRL, also conducted further studies concerned with a review of the then current and possible future uses of pipelines. He concluded that pipeline systems are capital-intensive and that the overall costs depend on how the primary installation is funded over the hypothetical life of the system. He also posited that due to the exploratory state of some of the technology, it was difficult to establish the capital cost very accurately. His proposed uses included the transportation of domestic refuse, aggregates and mineral wastes.

In a more recent and concise study, Howgego and Roe (1998) admit the difficulty in trying to identify possible sources of cost for the system. They concede that the system is both vaguely defined with areas of extensive possible variation and subject to very little development. They do, however, conclude that the monetary costs of the system could be broken down into three areas namely: construction, operation and return on capital with each of these options having multifaceted levels attached to them. They also state that cost does not necessarily imply monetary values because many included factors may be considered as intangible.

In conclusion, a 1997 recommendation made by the Engineering Council of the United Kingdom was that there should be an increase in pipelines, especially PCP, to solve the UK's transportation problems (Howgego, 2000). Following this recommendation however, there have not been any significant published research targeted towards achieving this objective except that published by Howgego and Roe (1998). There have also been calls for the reopening of the Mail Rail system to carry goods other than letters and small parcels. As well as the Metrofreight consortium detailed above, a similar suggestion has been made by the London Assembly (2003).

3.2. Europe

In terms of the development of capsule pipeline technology within Europe, the intention here is to focus upon the current status rather than provide a historical perspective. Weber and van Zuylen (2000) examine the readiness levels in Europe for a number of innovations within the transport field, both passenger and freight. Within this, they rate underground freight logistics as being between the test and first practical application phase. Since then, it is clear that some developments have advanced further.

The main activities that have been undertaken are:

- *CargoCap (Germany)*. This system resembles a small freight rail-car, or capsule that rolls through underground pipes or tubing (Beckmann, 2007). These capsules are then loaded with pallets, which are a standardized form in the transportation of goods between different international origin and destination routes. Each capsule is built to accommodate two pallets. This system was conceived from the need to free up German roads that were reaching their limits due to bottlenecks and delays. Daily, 10% of the 11,000 km of German motorways suffered from congestion (Stein and Schoesser, 2006). It was assumed by the researchers that if they could remove as much freight as possible from the highways, there would be adequate space for private users. Currently, a half scale test track has been developed to test prototype operations, with daily improvements being registered in the areas of the capsule air drag and reduction in energy costs.
- *Interdepartementale Projectgroep Ondergrondse Transport (IPOT, The Netherlands)*. In the midst of increasing international competition, the Aalsmeer flower auction, just outside Amsterdam sought to strengthen its market position in the decorative flower sector. With 19 million flowers traded daily and over 80% of these destined for customers abroad, the growing occurrences of congestion in and around Amsterdam as well as the airports threatened this goal. This increasing congestion near Amsterdam forced the government, in co-operation with business partners such as Schiphol Airport, the world's largest flower auction at Aalsmeer and logistics service providers to consider underground freight construction (van der Heijden et al., 2002). It was envisaged that using dedicated underground infrastructure would hasten the transportation of goods between the flower auction, the airport and the rail terminal at Hoofddorp. This concept culminated in the construction of electrical powered vehicles, called Automatic Guided Vehicles

Table 1
Summary of freight pipeline schemes within Europe.

System	Country	Commodity/product	Setting	Maturity	Status
BHRA/TRRL	UK	Not defined	Not defined	Prototype/testing	No longer exists
CargoCap	Germany	Palletised and/or consumer goods	Urban	Prototype/testing	Ongoing
Foodtubes	UK	Food	Urban/National	Conceptual	Ongoing
IPOT	Netherlands	Flowers/airport freight transfers between terminals	Airport/Urban	Prototype/testing	Ongoing
Mail Rail	UK	Parcels/letters	Urban	Working system	Closed
Metrofreight	UK	Palletised goods	Urban	Conceptual	Inactive
Pipeşnet	Italy	Small volume freight/consumer goods	Urban	Prototype/testing	Ongoing

(AGVs), travelling through underground tunnels at a speed of between 20 and 40 km/h. These vehicles were built to move as a single unit or in multiple units, similar to that of trains. These electrically powered vehicles were driven by computers, into which the individual destinations were previously programmed. With the successful prototyping and simulation of this concept for the use of the flower auction, its use for wider applications was recommended e.g. for use within congested urban cities and towns and for transporting freight around Schiphol Airport's 20 terminals (van der Heijden et al., 2002). Due to certain issues, political interests and well as financing, this concept is yet to be commercially deployed. Since 1997 and up till date however, the potential of this underground freight transport has been the subject of research by an interdisciplinary research group (Visser and van Binsbergen, 2000).

- Pipeşnet (Italy). With the construction of the first prototype in 2006, researchers from the University of Perugia (Italy) put to the test their previously conceived idea of transporting small volume freight through pipelines at high speeds and low friction. This focus on small volume freight is to avoid many of the critical issues innovative systems meet in their development such as construction complexity, overall size, safety requirements and so on (Cotana et al., 2008). Furthermore, in order to use a standardized unit of transport, the capsules for this system can be designed to fit one single sized euro-pallet (as opposed to two euro-pallets proposed by other systems). The mode of propulsion is achieved by linear electric synchronous motors which can recover some of its kinetic energy during deceleration. In order to reduce friction in long distance connections, magnetic levitation is envisaged as a solution to keeping the capsules in suspension to stop them from touching the surface of the pipelines. Typical goods which could be transported via this system include items which can be found in department stores. In this way, Cotana et al. (2008) envisage deliveries to individual homes, as do Howgego and Roe (1998). Other goods which could be transported may be work in progress products such as those from one industrial complex to another. The system, according to Cotana et al. (2008) is at an advanced concept stage having successfully carried out numerous research works and feasibility studies.

Table 1 summarises the above discussions, highlighting the various uses and applications for freight pipelines as proposed by the various researchers involved. While some of the systems were constructed for specific purposes and are used as such, others are more conceptual and can be customized for multiple functions.

4. Policy context

As stated by some scholars, underground networks cannot be entirely financed by private partners; public–private partnerships will be necessary (Binsbergen and Bovy, 2000). This was supported by Pielage (2001) while stating that, “if the governments should finance the infrastructure, as it does for roads, rails and waterways,

a profitable exploitation is possible”. Roop et al. (2002) however, stated that the private sector should not be expected to invest in this concept due to the absence of revenue generation from reductions in marginal truck costs. Lastly, Vance and Mills (1994) have suggested that totally private planning and development should be allowed since tube freight transportation is meant to provide a niche, general commodity service. They further admitted though, that this cannot be done without some legislative backing for example, access to federal rights-of-way. Stein and Schoesser (2006) were in support by stating also that the private sector take the initiative financially, but including the public in partnership agreements. Therefore, for capsule pipeline technology to be developed, it is important to examine current policy attitudes.

4.1. UK perspective

Table 2 summarises the main attitudes towards freight pipelines and innovative freight transport by policy makers. At the UK national level, it can be seen that there is no explicit mention of freight pipelines in any of the main documents, neither is there any mention towards innovative transport. Indeed, the general focus of all of these documents is to make improvements to the current transport networks that exist. Any innovations that are adopted are also within the context of this (as opposed to being a completely new mode). The only document which does refer more specifically to new technologies is Eddington (2006). However, the document is clear that the UK government should not be investing in anything which is not already in operation somewhere. Although not directly a policy document, reference should also be made to House of Commons Transport Committee (2008), a review on freight transport. While there is no reference to capsule pipelines in the main text, there is an appendix on the subject. Equally, there is a suggestion that funding should be made available for “low carbon vehicles of the future”. It is not clear whether capsules would qualify as “vehicles” but if so, there may be opportunities for development.

Conversely, within the English regions there is a more positive attitude towards capsule pipelines in certain regions.⁴ Both East Midlands Regional Assembly (2005) and Transport for London (2007) specifically talk about freight pipelines. While this may be expected for the latter, given the presence of Mail Rail, the former document is very positive about the concept (especially capsule pipelines) and actively looks to encourage its use within the region. Two other reports can be regarded as neutral towards capsule pipelines. South West Regional Assembly (2007) considers pipelines as having potential for the movement of china clay, while Government Office for Yorkshire and the Humber (2008) talks

⁴ Under the Regional Development Agencies Act (1998), nine Regional Assemblies were formed for England. Each has a statutory duty to produce a Regional Transport Plan, which includes a Freight Strategy. This document forms the basis for planning decisions within each Region and therefore forms the level of analysis for this study. A similar approach was adopted for the devolved governments (Scotland, Wales and Northern Ireland), who again have responsibilities to produce National Transport Plans and a freight strategy within this.

Table 2
Review of UK transport policy documents.

Policy document	Content from document referring to pipelines or new technologies for freight cargo	Attitude to capsule pipelines ^a	Comments
<i>UK National Level</i>			
Department for Environment, Transport and the Regions (1999) Sustainable Distribution: a strategy	References to new technologies and innovation, but only within the context of current operations. No mention of pipelines	–	Focus on road, rail and waterway and incremental technology developments, rather than completely new transport modes
Department for Transport (2004) The Future of Transport: a network for 2030	No references to pipelines or any other new and innovative modes of transport. However government wants to enable, promote and research innovative solutions	=	Statements show a willingness to adopt any form of transportation that offers superior benefits to those presently in use. However, there is an implication that innovation relates to current modes only
Eddington (2006) The Eddington transport Study: transports role in sustaining the UK's productivity and competitiveness	(1) "However, some of the most exciting prospective technologies are undeveloped or untested and carry significant uncertainties and risks around cost, deliverability, public acceptability and the scale of benefits" p. 31, sec 1.75a (2) "Instead, the right answer is to create a policy framework that will encourage technological innovation... and to make sure policy does not make expensive mistakes by pursuing untried and untested technologies" p. 31, sec 1.75b	–	An operational system is needed, from which studies can be conducted using 'real data' before any commitment can be made towards this technology in the UK
Department for Transport (2007) towards a sustainable transport system	No references to capsule pipelines. No reference either, to finding more innovative forms of transport. Reference is made however, to finding more efficient use of current infrastructure through good regulation and road pricing	–	Very much focused on making best use of road and rail modes
Department for Transport (2008a) delivering a sustainable transport system: the logistics perspective	Reflects the "towards a sustainable transport system" document, with no mention of innovative forms of transport. Instead, there is a focus on making better use of the current infrastructure	–	Focuses upon making best use of current freight transport networks
<i>English Regional Level</i>			
East Midlands Regional Assembly (2005) East Midlands Regional Freight Strategy	(1) "The Strategy will seek to facilitate greater use of this sustainable mode (pipelines) and will keep an eye on technical progress in Cargo Pipelines" pp. 6 (2) "Promote knowledge and understanding of the role and potential of pipelines... including any future role for cargo pipelines" pp. 26,29 Key Policy 7	++	One of two regional freight strategies to mention explicitly cargo pipelines and encourage their use
East of England Regional Assembly (2008) Regional Freight Strategy for the East of England Region	Has a goal to "Help increase business investment and innovation by supporting economies of scale or new ways of working." (p. 13) but does not clarify the exact meaning. No mention of pipelines.	–	Innovation particularly in the context of current surface modes
Government Office for the South East (2004) Regional Transport Strategy	No mention of pipelines or innovative transport modes. Focused on current surface modes	–	No tangible evidence to reflect position on capsule pipelines, but focus suggests support for 'traditional' modes
Government Office for Yorkshire and the Humber (2008) The Yorkshire and Humber Plan	"Support future pipeline developments where these provide opportunities to reduce freight by surface modes" (p. 190)	=	There could be support if a business case is made. Not specifically related to capsule pipelines
North East Assembly (2008) The North East of England Plan Regional Spatial Strategy to 2021	No mention of pipelines or innovative transport modes. Focused on current surface modes	–	No tangible evidence to reflect position on capsule pipelines, but focus suggests support for 'traditional' modes
North West Freight Advisory Group (2003) North West Regional Freight Strategy	No mention of pipelines or innovative transport modes. Focused on current surface modes	–	No tangible evidence to reflect position on capsule pipelines, but focus suggests support for 'traditional' modes
South West Regional Assembly (2007) The Draft Regional Spatial Strategy for the South West 2006–2026	Would consider pipelines for the movement of china clay waste (p. 164)	=	Very limited application and may not be capsule based. In Japan, minerals are transported by capsule pipeline (ASCE, 1999)
Transport for London (2007) London Freight Plan – sustainable freight distribution: a plan for London	"Underground freight pipelines are used at airports for baggage handling". Furthermore, "this technology is being considered by other major world class cities and in the long term could provide a fast, reliable and economic retail distribution system for London as surface congestion increases" pp. 55	+	This statement infers the willingness to adopt the capsule pipeline technology should the opportunity arise
West Midlands Regional Assembly (2007) Regional Freight Strategy	Only references pipelines in the context of the distribution of petroleum products	–	Considers pipelines for current products only
<i>Devolved Governments</i>			
Scottish Executive (2006) The Freight Action Plan for Scotland	Pipelines identified as a transport mode but nothing in the strategy about increasing their use, or introducing innovative transport modes	–	No tangible evidence to reflect position on capsule pipelines, but focus on making better use of current modes
Welsh Assembly Government (2008) The Wales Freight Strategy	The document states that, "furthermore, 'futuristic' ideas including sending solid freight in containers	++	Some support for the idea, in terms of supporting the development by potential users, but no direct

(continued on next page)

Table 2 (continued)

Policy document	Content from document referring to pipelines or new technologies for freight cargo	Attitude to capsule pipelines ^a	Comments
	enclosed in cylindrical vacuum capsules along pipelines using pneumatics or magnetism have also been suggested" (p74)The strategy document makes clear, in their 'steps towards delivery', to "Promote the potential role of pipelines among possible users, in particular in seeking to make innovative use of pipelines or seeking new opportunities" (p76)		commitment. Similar position to East Midlands Regional Assembly
Department for Regional Development (2002) Regional Transportation Strategy for Northern Ireland 2002–2012	No mention of pipelines within the strategy, while innovation is generally mentioned within the context of public transport	–	Focused on making better use of the current transport resources such as road and rail

^a ++ very positive; + positive; = neutral; – negative; ––very negative.

about using pipelines to replace surface transport. The key here is to demonstrate a business case. What is interesting to note is that the majority of documents do not even refer to pipelines for the distribution of gas/liquids. The overall focus of all the documents is the improvement of the surface transport networks.

A similar picture emerges for the devolved governments, with only Wales specifically mentioning capsule pipelines, and adopting a similar tone to *East Midlands Regional Assembly (2005)*. However, there is no direct commitment to funding a capsule pipeline network. Again, the main focus is upon improving the current transport network.

4.2. European perspective

Turning to European policy, it is important to consider both strategies made at an EU and national level. Much of current European policy is underpinned by the 2001 White Paper setting out transport policy to 2010 (*European Commission, 2001*). This stresses the importance of improving current transport networks, with the use of innovations (as opposed to innovative transport modes) as appropriate. As with the UK, there is little coverage of pipelines and no specific mention of capsule pipelines.

This theme of improving current networks is also found within the main policy documents for individual countries identified through the research. For many countries, there are no references to innovation either – examples include Finland (*Ministry Of Transport And Communications, 2008*) and Luxembourg (*Ministère des Transports, 2007*). By contrast some countries do make mention of innovation, but this again reflects the context of current transport networks rather than developing new transport modes. Examples here include Germany (*bmvbs, 2008*) and Austria (*bmvit, 2002*). In the case of the latter, transport is actually contained within the same government department as innovation. Consequently, a strategy exists to link innovation and transport (*bmvit, 2008*), although none of the initiatives within this strategy are currently suited to the development of freight pipeline technology. Finally, the Republic of Ireland perceives itself as a "technology taker" (*Department of Transport, 2009*), adopting new ideas that have been developed elsewhere. This implies that any application of freight pipelines would have to be firstly demonstrated elsewhere.

4.3. Discussion

Based on the above, some comments can be made about the current status of freight pipelines and any related technology. From a technological perspective, it could be considered that the UK has regressed, having had an operational subterranean system (Mail Rail), and the test track at Milton Keynes. Equally, these fail-

ures may reflect the difficulty in justifying the existence of such a system. Mail Rail served a dedicated purpose and was well integrated into the postal distribution network. Once this network changed, it became more challenging to support as, in effect, the underground freight journey had to become part of an intermodal trip, with a significant impact on costs. The lack of flexibility also meant that other goods could not be carried. Therefore, future applications in the UK need to take into account supply chain structures, the need to form part of an intermodal transport chain and offer flexibility in terms of the products carried. Being able to carry palletised goods would potentially contribute towards this flexibility.

However, the UK policy environment is such that, currently, any technological developments will need to be led by the private sector. Very little governmental support was found for freight pipelines or related innovative transport modes. This may well create challenges, especially in constructing the network as this may well require engagement with policy makers. Equally, it is suggested that a business case needs to be made before public sector investment could occur (for example, *Eddington, 2006*). To do this, it is highly likely a working system is needed. With the dearth of such research accomplishments in the UK sector, it is likely that this development may take place further afield, such as in other countries in Europe, America and even Asia. In that regard, the position of technology taker (like the Republic of Ireland) will be adopted.

Within Europe, there are several schemes that have reached an advanced stage, with demonstrators being developed. Although some of the activities have received research funding through the EU, it is clear that any further developments will require private sector involvement only, as generally policy makers are focused on the current transport network. Indeed, it could be argued that to develop a full size system, the support of policymakers is needed (for example, through planning regulations). Therefore, a 'glass ceiling' in development may have been reached until perceptions change. Perhaps the best example of this is in the Netherlands, where the underground AGV scheme was almost ready to be implemented, but could not get support from policy makers to actually be introduced. Therefore, it can be seen that the policy environment is similar to the UK.

It is also interesting to note that, within Europe, the main developments have all been focused around deliveries within an urban environment. This contrasts with the rest of the world, where the majority of initiatives have been focused upon industrial environments, and particularly the movement of mining products. Examples include Sumitomo Metal Industries (*Liu, 2007*), TubeXpress (*Vandersteel, 1980; Vandersteel et al., 1997*), Transprogress (*Goff et al., 2000; Pielage and Rijsenbrij, 2005*) and Pneutrans (*Weaver, 1999; Hodson, 2008*). This suggests that maybe there is a need

within the UK and Europe to reconsider where freight pipelines may be able to offer more significant benefits.

5. The benefits of capsule pipelines

Despite the seemingly negative policy perception towards capsule pipelines, it is interesting to note that some schemes have reached an advanced stage. This suggests that there are a number of benefits from capsule pipeline technology which enable them to meet business and policy objectives. Based on a synthesis of the policy documents, some key aspects have been identified and the potential role for capsule pipelines is discussed. While a UK focus is taken, many aspects apply across Europe.

- **Reliability.** The possibility for a reduction in congestion on urban highways would provide through improved reliability and enable freight movement to be better managed (Eddington, 2006). This sentiment is echoed by Transport for London (2007), who state that “the growing number of vans may play a greater role than HGVs in adding to peak period congestion, where the impact of congestion is to reduce journey time reliability”. This unpredictability associated with current modes of transport is tackled by pipelines owing to their electronic and computerized controls as well as their unimpeded movements in the dedicated underground infrastructure. Delivery times are better predicted and goods are adequately tracked.
- **Environment.** With the increased focus on climate change, there is a need to fully assess the environmental benefits of capsule pipelines. It is assumed that due to the use of electric energy, there will be little or no emissions from the use of freight pipelines given an increasing focus on using nuclear and renewable sources of electricity. In the context of this paper, it is interesting to note Stern (2006), who comments:
 - “policies are required to support the development of a range of low carbon and high-efficiency technologies on an urgent timescale” and
 - “greater international co-operation to accelerate technological innovation and diffusion will reduce the cost of mitigation”.

In the case of capsule pipelines, the current state of technology makes the latter point particularly relevant.

- **Safety and security.** Road freight crime is an ongoing problem which has an estimated cost of £250 million to the UK economy annually (TruckPol, 2008). This of course, has its effects on manufacturing as well as retailers who would encourage any mode of transportation that will reduce the risks of theft. Safety – wise, although the number of accidents involving road freight vehicles continues to decrease, 10,700 HGVs and 14,600 vans carrying goods were involved in road accidents (Department for Transport, 2008b). By being enclosed underground, capsule pipelines offer an improvement in the safety of people and the security of goods.
- **Delivery times.** Logistics operators have a desire for 24 h delivery times. However, the general public’s perception of a lorry or a truck is that they do not want them on the road. Therefore, schemes exist to restrict the movement of lorries in urban areas (House of Commons Transport Committee, 2008). Limiting truck movements during the day reduces congestion and pollution while limiting their movements at night reduces occurrences of noise, disturbance and security. This has raised some concerns from retailers, logistics companies and trade associations over the impact on operations (Browne, 2005), and requires a balanced approach. Freight pipelines, however, are

unseen and unobtrusive but efficient and reliable, and therefore it is possible that goods may be delivered anytime within the 24-h window. This is exemplified by the Mail Rail system which was in operation for 19 h daily, delivering mails across London (Karslake, 2008).

- **Transport Costs.** Due to the complete automation of this system, there may be a reduction in man-handling costs, as well as driver costs. This absence of the human interface will reduce the costs involved in truck transportation. Again, there will be a fixed annual operating cost. The use of advanced scheduling techniques also makes it possible to reduce unused infrastructure capacity hence maximizing it (Clarke, 1993). However, there may be minimum requirements in the distribution network to achieve these savings (Zandi et al., 1976). Given that the freight pipeline may form part of an intermodal transport flow, these cost savings will need to exceed the additional handling costs for transfer to/from the pipeline.

6. Challenges with capsule pipelines

There are also a number of challenges for capsule pipeline technology to overcome before it can be adopted more widely.

- **Technology acceptance.** One of the challenges is the acceptance of the technology as a viable alternative to conventional transport modes, where the possible use of the freight pipeline transport can be utilized as opposed to the more conventional modes such as road transportation. In such cases, it is not envisaged that this technology will completely replace other forms of transport but work in tandem with them to best optimize the transportation network (Ebben, 2001). While this optimization is necessary, certain challenges exist with the use of this technology.
- **Intermodal transfer with existing modes.** Ebben (2001) has noted that any automatic transport system (such as capsule pipelines) will need to interface with other transport modes, and that the boundary for the design of such a system needs to include this interface. The efficiency and seamless transfer of goods at the interchange facilities as well as the increase in product handling instances are of concern. While these may serve as potential barriers to the adoption of this technology, a certain level of trade-offs or a balancing of priorities may be applied here. These trade-offs, according to Voss (2007) are a constant requirement by stakeholders when considering competing short and long-term priorities. These may include managing these multiple product handling instances and interchange facilities to the best possible level of efficiency so that as much traffic as possible can be taken off the roads to minimize the effects of environmental pollution. These interchange facilities should not however affect the just-in-time delivery windows for goods as this system is ideated to be in operation for close to 24 h daily and operate at speeds in excess of current modes.
- **Support for adoption.** This paper has already demonstrated the general lack of interest from policy makers. This may be considered to be a major hurdle as the absence of the ‘political push’ may be a stifling factor towards implementation. Industry will also need to be convinced, especially if they are likely to be providing the majority of funding for such schemes. This reflects ownership with current gas and liquid pipelines, where in the majority of circumstances the operator owns the infrastructure. Some promoters argue that the benefits are not fully understood (for example, Miles and Loose, 2008), while Howgego and Roe (1998) have raised the challenge of stakeholders not fully perceiving in the present, issues that may arise in the future. However, there are also significant risks in supporting new technologies.

- *Costs and funding.* Linked to the acceptance issue is funding. Investment costs can be regarded as a main influencing factor for underground infrastructure planning (Gordijn, 1999). Other researchers (see Butler, 1978; James, 1980; Howgego and Roe, 1998) make reference to the relative costs involved in this venture. In developing a capsule pipeline network, there will be significant sunk costs in delivering the infrastructure and so it is essential the network offers a long term transport solution. Obtaining this funding however, will only be possible as the technology proves itself. Operating costs will then be dependent upon maintaining a constant flow of products through the pipeline.
- *Design and construction.* Certain design issues constitute challenges associated with the acceptance of capsule pipelines. Owing to the fact that this infrastructure is capital-intensive as well as subterranean, any alterations in infrastructure planning will be costly and time consuming. A further disadvantage for freight pipelines is that the modal transfer needs to overcome the height difference between the tunnel and surface (Binsbergen and Bovy, 2000). This will add to overall costs and may affect the viability of the freight pipeline as a transport mode. Other design issues relate to the tubes which need to be as straight as possible (ASCE Task Committee, 1999). Kalman and Klinzing (2005) have however shown that although bends and elbows could cause some difficulties in pneumatic conveyance, they play vital roles in giving pneumatic conveying systems considerable flexibility by allowing routing and distribution. Arends and Grote (2000) in their submission further highlighted the difficulties in constructing curves in pipelines via the preferred technique of pipejacking for underground logistics systems. They also suggest special demands for the construction of these pipelines especially when taking into consideration, operational demands like vibrations of the motors when in motion. This according to them is a new field of study not yet covered in design rules. In many developed areas today, there are networks of tunnels for both utilities and also underground passenger transport. Therefore, building new tunnels may prove challenging. However, the re-use of disused tunnels (such as Mail Rail in London) may offer a solution. A final design issue is determining capacity as, once built, there is a finite limit to capacity before additional tunnels need to be bored.
- *Competition.* Finally, there is the issue of competition against the established transport modes. In particular, the networks needed for traditional modes are often already provided and therefore the significant start-up costs have already been incurred. Equally, these modes are well recognised by industry and fit well with current distribution practices. The challenge for freight pipelines is to offer a solution that can complement these modes.

7. Conclusion and paths for future research

The literature shows a trend towards two broad facets, when considering the utilization of this concept within the transportation arena. These are operational and policy aspects. The operational aspects are concerned with the efficiency, engineering and practicality of the system, while the policy issues include the attitudes of the government, society and legal matters concerned with the use of these systems.

7.1. Operational aspects

The studies show the trend towards utilizing this concept within a closed transport network. This network will consist of a fixed number of origin–destination locations, which are connected by underground pipelines. For example, the Mail Rail system operated

over a distance of about 7 miles across nine stations. Replicating similar systems across corridors in cities or regions with high freight volumes may offer benefits the present conventional modes do not. This is indicative from a statement by Royal Mail showing that taking the underground system out of operation meant adding an extra 80 vans to London roads weekly (London Assembly, 2003). This is the opposite of its successful debut when a year after it was constructed, a quarter of London's mail vans disappeared from the streets (Trench and Hillman, 1996).

Applying this concept to supply chains, to seek the benefits thereof is important and represents an important path for future research. The development of quantitative models to evaluate the ability of pipelines to provide effective transport solutions is worthy of being pursued. While some modelling of freight pipelines (Roop et al., 2001; van der Heijden et al., 2002; Versteeg and Verbracke, 2005) have taken place, there is a need to take into account more fully the dynamic nature of supply chains, where demand can vary by day of the week and hour of the day. Such modelling will enhance understanding of the real benefits capsule pipelines can bring, especially if constraints on road transport (such as delivery windows) are included. The use of modelling techniques may also prove useful for comparing the different applications of capsule pipelines, as discussed in Section 6.

Further, barriers such as system robustness, reliability and capacity need to be evaluated to determine the level of advantage over the conventional transport modes. This presents an important area of study because without the obvious advantages over conventional modes of transportation, this innovative transport mode will not be marketable to the proposed users.

7.2. Policy aspects

This innovative concept aims to achieve a more effective organisation of freight transportation, resulting in a more rational use of the current transport infrastructure, presently prone to overload. This overload has caused congestion and pollution, with continued calls by stakeholders for solutions towards alleviating these challenges.

The promotion and introduction of advanced transportation technologies into the transportation sector is not the sole responsibility of researchers and innovators, but the shared responsibility of governments, policy makers as well as businesses and the society at large. It has however been shown that both authorities and the public have barriers against different advanced transport technologies for various reasons. This is seen through a lack of investments or funding towards more targeted research in this area. It has also manifested itself through a lack of general user acceptance, even after the few successful systems in operation.

This may suggest a new area of study, seeking to understand the wider implications of this innovative concept and may require interviews with relevant personnel in academia, government, industry and the general public. These may be conducted on a one-to-one basis or within the context of focus groups.

To conclude, this paper has presented a critical review of the current status of freight pipelines in the UK and Europe. While the idea may currently seem like science fiction, our research has found demonstrable examples where the system has been used successfully. In order to be more widely adopted, there are a number of conditions that need to be met, particularly in relation to the cost of developing a network. There is also no clear direction as to the appropriate situation for their use. From a policy perspective in the UK, currently there is no support for introducing new technology at a national level, but certain regional governments have expressed interest in the idea. This view also appears to be reflected at a European level. This suggests that the further development of technologies within this region may prove to be challenging.

In the short term, potential new applications of capsule pipeline technology appear to lie in aggregate and urban environments (based on current use or published research studies), and particularly for shorter distance networks. The use of magnetic levitation (Maglev) technology for propulsion and vacuum tubes offers a long term opportunity to significantly reduce time for transport, particularly over medium and long distances. This could lead to underground pipeline networks across regions, or even between continents. This would bring to fruition the vision outlined in Beecroft et al. (2003). Kidd (2008) has highlighted Maglev opportunities on the Eurasian landbridge (for surface transport between Europe and Asia). Putting the infrastructure inside vacuum pipes could offer greater opportunities in terms of higher speeds and/or lower energy costs. The challenges from infrastructure costs and political will to achieve this would appear to be immense.

References

- Arends, G., Grote, B.J.H., 2000. Underground logistics systems versus Trenchless Technology. In: Proceedings from the 2nd International Symposium on Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems. September 28–29, Delft, The Netherlands.
- ASCE Task Committee, 1999. Freight pipelines: current status and anticipated future use. *Journal of Transportation Engineering* 12 (4), 300–310.
- Baker, P.J., Hawrych, J.R., 1982. Pneumatic capsule pipeline system research and development in the UK. *Journal of Pipelines* 2, 237–249.
- Basset, S., 2001. Freight Tunnels Planned for London. <<http://www.building.co.uk/story.asp?storycode=1012867>> (accessed 20.11.08).
- Beckmann, H., 2007. CargoCap: a new way to transport freight. In: Conference Proceedings of the Schiller Institute Conference, Kendrich, Germany. September 15–16, 2007. <http://www.schillerinstitute.org/conf-iclc/2007/landbridge_conf_beckman.html> (accessed 22.11.08).
- Beecroft, M., Lyons, G., Chatterjee, K., 2003. Transport Visions: Freight and Logistics. Landor, Transport Visions Reports 7. London, UK, 65pp.
- Binsbergen, A.J., Bovy, P., 2000. Underground urban goods distribution network innovation. *The European Journal of Social Sciences* 13 (1), 111–128 (Routledge).
- bmvs (Bundesministerium für Verkehr, Bau und Stadtentwicklung). 2008. Freight Transport and Logistics Masterplan, Die Bundesregierung, Berlin.
- bmvit (Bundesministerium für Verkehr, Innovation und Technologie). 2002. Generalverkehrsplan Österreich 2002, January 2002. <<http://www.bmvit.gov.at/verkehr/gesamtverkehr/generalverkehrsplanung/downloads/gvk.pdf>> (accessed 03.03.09).
- bmvit., 2008. IV2Splus – “Intelligent Transport Systems and Services plus”. <<http://www.bmvit.gov.at/en/innovation/mobility/index.html>> (accessed 03.03.09).
- Brennan, J., 2005. Beach Pneumatic. <<http://www.columbia.edu/~brennan/beach/chapter2.html>> (accessed 14.03.08).
- Browne, M., 2005. Night-time Delivery Restrictions: A Review. City Logistics Conference, July 2005.
- Butler, P., 1978. The Cost of Sending Material in Capsules Through the Pipeline. *The Engineer*, 6th April, pp. 62–63.
- Clarke, M., 1993. Metro Freight: The Automation of Freight Transportation. Cranfield School of Management.
- Cotana, F., Rossi, F., Marri, A., Amantini, M., 2008. Pipeşnet: innovation in transport through high rate small volume payloads. In: Proceedings from the 5th International Symposium on Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems, 2008. The University of Texas, Arlington, March 20–22.
- Department for Regional Development. 2002. Regional Transportation Strategy for Northern Ireland 2002–2012. <http://www.drni.gov.uk/rts_main_doc-2.pdf> (accessed 12.12.08).
- Department for Transport. 1999. Sustainable Distribution: A Strategy. <<http://www.dft.gov.uk/pgr/freight/sustainable/sustainabledistributionastrategy>> (accessed 13.12.08).
- Department for Transport. 2004. The Future of Transport: A Network for 2030. The Stationery Office, London.
- Department for Transport. 2007. Towards a Sustainable Transport System: Supporting Economic Growth in a Low Carbon World. The Stationery Office, London.
- Department for Transport. 2008a. Delivering a Sustainable Transport System: The Logistics Perspective. The Stationery Office, London.
- Department for Transport. 2008b. Goods Vehicle Accidents and Casualties. Road Accident & Road Freight Statistics Factsheet No. 1 – 2008. <<http://www.dft.gov.uk/pgr/statistics/datatablespublications/accidents/casualtiesgbar/supplettablesheets/flagchgvfsheet.pdf>> (accessed 16.12.08).
- Department of the Environment, Transport and the Regions, DETR. 1999. Sustainable Distribution: A Strategy. The Stationery Office, London.
- Department of Transport. 2009. Smartertravel – A Sustainable Transport Future: A New Transport Policy for Ireland 2009–2020. Department of Transport, Dublin.
- East Midlands Regional Assembly. 2005. East Midlands Regional Freight Strategy. <<http://www.emra.gov.uk/files/file780.pdf>> (accessed 12.12.08).
- East of England Regional Assembly. 2008. Regional Freight Strategy for the East of England Region. <<http://www.eera.gov.uk/publications-and-resources/studies/transport-studies/consultation-of-regional-freight-strategy-and-optioneering-report>> (accessed 12.12.08).
- Ebben, M., 2001. Logistic Control in Automated Transportation Networks. PhD Thesis, Twente University, Netherlands.
- Eddington, R., 2006. The Eddington Transport Study: Transport's Role in Sustaining the UK's Productivity and Competitiveness. The Stationery Office, London.
- European Commission. 2001. European Transport Policy for 2010: Time to Decide, Office for Official Publications of the European Communities, Luxembourg.
- Goff, Z.A., Patil, S., Shih, C.S., 2000. Feasibility of Freight Pipelines to Relieve Highway Congestion. Report 1803-1. Texas Transportation Institute, The Texas A&M University San Antonio, Texas and The Texas Department of Transportation, Research and Technology Transfer Section, July 2000.
- Gordijn, H., 1999. Underground Freight Transport in the Netherlands in the Next Century. The National Spatial Planning Agency, The interdepartmental Task Force for Underground Transport, The Hague, Netherlands.
- Government Office for the South East, 2004. Regional Transport Strategy. Regional Planning Guidance for the South East RPG9. TSO, London (Chapter 9).
- Government Office for Yorkshire and the Humber. 2008. The Yorkshire and Humber Plan: Regional Spatial Strategy to 2026. <http://www.goyh.gov.uk/497763/docs/199734/199799/689582/1_Y_H_Published_RSS_May_2008.pdf> (accessed 12.12.08).
- Hayhurst, J.D., 1974. The Pneumatic Post of Paris. <<http://www.cix.co.uk/~mhayhurst/jdhayhurst/pneumatic/book1.html>> (accessed 28.04.08).
- Hodson, N., 2007. Pneumatic Transport – State of the Art – Desk research. <http://www.noelhodson.com/index_files/StateoftheArt-foodtubes2FEB07.htm> (accessed 15.04.08).
- Hodson, N., 2008. Foodtubes. Energy saving pipeline capsule goods transport. In: Proceedings from the International Symposium on Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems. ISUFT 2008, Arlington, Texas, March 20–22, 2008.
- House of Commons Transport Committee, 2008. Freight Transport. Eighth Report of Session 2007–08. The Stationery Office Limited, London.
- Howgego, T., Roe, M., 1998. The use of pipelines for the urban distribution of goods. *Journal of Transport Policy* 5, 61–72.
- Howgego, T., 2000. Capsule Pipelines – Early Developments. <http://www.capsu.org/history/early_developments.html> (accessed 01.04.08).
- James, J., 1980. Pipelines considered as a mode of freight transport. A review of current and possible future uses. *Environmental Geochemistry and Health* 2 (1), 1–25.
- Kalman, H., Klinzing, G.E., 2005. Freight Pipelines – 2005 Review. Reviews, International Freight Pipeline Society. <<http://www.freightpipeline.org/publications.htm>> (accessed 29.11.09).
- Karslake, C., 2008. Mail Rail. <<http://www.mailrail.co.uk/>> (accessed 03.02.08).
- Kidd, J., 2008. High Speed Maglev Logistics. Is This The ‘Golden Goose’ We Are Looking For? In: Proceedings from the 13th International Symposium on Logistics, Bangkok, Thailand, July 6–8, 2008.
- Liu, H., 2007. Research, development and use of PCP in the United States of America. *Japanese Journal of Multiphase Flow* 21 (1), 57–69.
- London Assembly, 2003. The Future of Mail Rail: A report by the London Assembly's Public Services Committee, Greater London Authority, London.
- Miles, R., Loose, B., 2008. Sizing the Prize, Presenting the Case for Freight Pipelines. In: Paper presented at the 4th International Symposium on Underground Freight Transport (ISUFT), Dallas, March 20–22, 2008.
- Ministère des Transports, 2007. mobil 2020: Mobilité et développement durable. Ministère des Transports, Luxembourg.
- Ministry of Transport and Communications, 2008. Transport Policy Guidelines and Transport Network Investment and Financing Programme Until 2020 Government Transport Policy Report to Parliament, Helsinki. <http://www.lvm.fi/c/document_library/get_file?folderId=38357&name=DLFE-1704.pdf&title=Transportpolicyguidelines> (accessed 03.03.09).
- North East Assembly, 2008. The North East of England Plan Regional Spatial Strategy to 2021, TSO, London.
- North West Freight Advisory Group. 2003. North West Regional Freight Strategy. <http://www.nwrpb.org.uk/documents/?page_id=4&category_id=111> (accessed 12.12.08).
- Pepinster, C., 1997. Oxford Streets deliveries to Go Underground. *The Independent (London)* August 10, 1997. <http://findarticles.com/p/articles/mi_qn4158/is_1_n14120174> (accessed 20.12.08).
- Pielage, B.A., 2001. Underground freight transportation. A new development for automated freight transportation systems in the Netherlands. In: Proceedings of the IEEE Intelligent Transportation Systems, Oakland, CA, 2001, pp. 762–767.
- Pielage, B., Rijsenbrij, J., 2005. Developments in underground freight transportation. In: Konings, R., Priemus, H., Nijkamp, P. (Eds.), *The Future of Automated Freight Transport: Concepts, Design and Implementation*. Edward Elgar Publishing, UK, pp. 65–84 (ISBN 1-84542-239-2).
- Roop, S.S., Roco, C.E., Morgan, C.A., Olson, L.E., Warner, J.E., Kang, D., Bierling, D.H., 2002. The Technical and Economic Feasibility of a freight pipeline system in Texas – Year 3 Report. Report No. 1519 – 3, Texas Transport Institute, Texas A&M University, College Station, Texas.
- Roop, S.S., Olson, L., Warner, J.E., Morgan, C.A., Bierling, D.H., Roco, C., Kneepkens, R., DeSward, R., Rahimian, M., Toliyat, H., Shultz, K., Rediniotis, O., 2001. The Technical and Economic Feasibility of a Freight Pipeline System in Texas – Year 2 Report. Report No. 1519 – 2, Texas Transport Institute, Texas A&M University, College Station, Texas.

- Scottish Executive. 2006. The Freight Action Plan for Scotland – Preparing For Tomorrow, Delivering Today: Freight. <<http://www.scotland.gov.uk/Resource/Doc/154893/0041640.pdf>> (accessed 12.12.08).
- Self, D., 2004. Pneumatic Networks. <<http://www.dself.dsl.pipex.com/MUSEUM/COMMS/pneumess/pneumess.htm>> (accessed 20.02.08).
- South West Regional Assembly, 2007. The Draft Regional Spatial Strategy for the South West 2006–2026. <<http://www.southwest-ra.gov.uk/media/SWRA/RSS%20Documents/Final%20Draft/draftrssfull.pdf>> (accessed 12.12.08).
- Stein, D., Schoesser, B., 2006. CargoCap – Transportation of Goods Through Underground Pipelines: Research Project in Germany. In: International Conference on Pipeline Engineering and Construction, Baltimore, Maryland, USA, July 13–16.
- Stern, N., 2006. The Economics of Climate Change. The Stern Review. Cambridge University Press, Cambridge.
- Telefonica, 2008. Prague's Pneumatic Post. <http://www.cz.o2.com/soho/en/5469-o_cem_se_mluyi/potrubni_posta.html> (accessed 14.04.08).
- Transport for London, 2007. London Freight Plan – Sustainable Freight Distribution: A Plan for London. <<http://www.tfl.gov.uk/assets/downloads/businessandpartners/London-Freight-Plan.pdf>> (accessed 12.12.08).
- TruckPol, 2008. <<http://www.truckpol.com/index.htm>> (accessed 30.04.08).
- Trench, R., Hillman, E., 1996. The nerves of the city. In: London Under London. A Subterranean Guide, New ed. London. Butler and Tanner Ltd. Frome and London, pp. 165–191.
- van der Heijden, M.C., van Harten, A., Ebben, M.J.R., Saanen, Y.A., Valentin, E.C., Verbraeck, A., 2002. Using simulation to design an automated underground system for transporting freight around Schiphol Airport. *Interfaces* 32, 1–19.
- Vance, L., Mills, M.K., 1994. Tube Freight Transportation. <<http://www.tfsrc.gov/pubrds/fall94/p94au21.htm>> (accessed 01.02.08).
- Vandersteel, W., 1980. Tubexpress. <www.tubexpress.com/tubexpress.htm> (accessed 13.03.08).
- Vandersteel, W., Zhao, Y., Lundgren, T.S., 1997. Automating movement of freight. Transport research record. *Journal of the Transport Research Board* 1602, 71–76.
- Versteegt, C., Verbraeck, A., 2005. Supporting the design of automated transportation systems using innovative simulation. In: Konings, R., Priemus, H., Nijkamp, P. (Eds.), *The Future of Automated Freight Transport: Concepts, Design and Implementation*. Edward Elgar Publishing, UK, pp. 169–186 (ISBN 1-84542-239-2).
- Visser, J., van Binsbergen, A., 2000. Underground logistical systems in cities: a visualization of the future. In: Proceedings from the 2nd International Symposium on Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems, September 28–29, Delft, The Netherlands.
- Voss, C.A., 2007. Learning from the first operations management textbook. *Journal of Operations Management* 25 (2), 239–247.
- Weaver, P.B., 1999. Single line reversing system capsular pneumatic freight pipelines. In: Proceedings from the 16th Annual International Pittsburgh Coal Conference, PA (US), September 11–15, Pittsburgh, United States of America.
- Weber, K. M., van Zuylen, H., 2000. European Policy for Technology Innovation in Transport: Finding the Right Role and the Right Options. The Institute for Prospective Technological Studies Report, Issue 48. <<http://ipts.jrc.ec.europa.eu/home/report/english/articles/vol48/TRA1E486.htm>> (accessed 03.03.09).
- Welsh Assembly Government, 2008. The Wales Freight Strategy. <<http://wales.gov.uk/deet/publications/transport/wfs/wfsfull.pdf?lang=en>> (accessed 12.12.08).
- West Midlands Regional Assembly, 2007. Regional Freight Strategy. <<http://www.wmra.gov.uk/documents/Transport/Freight%20Strategy%20FINAL.pdf>> (accessed 12.12.08).
- Winkelmans, W., Notteboom, T., 2000. In search of a strategic positioning of underground transport by pipes or tubes in the framework of a coherent transport policy. In: Proceedings from the 2nd International Symposium on Underground Freight Transportation by Capsule Pipelines and Other Tube/Tunnel Systems, September 28–29, Delft, The Netherlands.
- Zandi, I., Allen, W.B., Morlok, E.K., Gimm K. K., Plaut, T., Warner, J., 1976. Transport of Solid Commodities via Freight Pipeline – Freight Pipeline Technology – vol. I. Department of Civil and Urban Engineering, University of Pennsylvania, Pa for Department of Transportation. Report No. DOT-TST-76T-35.
- Zandi, I., Gimm K.K., 1976. Transport of Solid Commodities via Freight Pipeline – Freight Pipeline Technology – vol. II. Department of Civil and Urban Engineering, University of Pennsylvania, Pa for Department of Transportation. Report No. DOT-TST-76T-36.