Methods of Transport Technologies: A Review On Using Tube/Tunnel Systems

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Abstract. This review covers different ways of transporting goods through tubes and tunnel systems and summarizes their technologies from a mechanical engineering point of view as well as provides a synopsis of the works over the past three decades which were carried out all over the world. The review explored their implementation possibilities in order to meet the high demand of fast and reliable transportation system, especially in big cities. Such of the new system may provide and offer many environmental and safety benefits, such as reducing traffic jams, accidents, air pollution. It had been found that many research and developments concerning the transport technologies have been accomplished. Basically, there are two transportation systems that can be adapted for transporting goods, people, and variously freights through a tube or tunnel, namely pneumatics air tube base, and magnetic levitation approach. The progress of these approaches is discussed in this paper.

1. Introduction
The transport of people and goods from one place to another cannot be avoided in the lifestyle of the modern society. Such movements are almost increasing from year to year. As a result, traffic jams often occur in various transportation routes and delivering goods to shopping centers on time are often disturbed. This condition will give loses on the marketability of goods which having a short lifetime, such as vegetables, fruits, and fresh fish and among others.

It had been recognized that transportation systems are crucial for fostering the economic growth in any country around the world. Currently, transportation systems commonly involve route transportation, such as a railway system and road vehicle system. Another transportation system mechanism of goods and people is through the use of air tunnel. This approach does not interfere with existing railway or road vehicle systems. Therefore, using the air tunnel eventually reduces route traffic jams and provide a rapid system in delivering goods to various destinations.

The new generation, transportation system, involves certain requirements such as rapidity, reliability, and safety. In addition to this, it should be convenient, environment-friendly, low maintenance, compact, lightweight, and suited to mass transportation. The transportation system which uses friction between wheels and rails, in the future may be handicapped by the presence of noise/vibration, traffic problems, limited capacity and no foreseeable labor productivity improvement [1]. Therefore, transportation system using tube or tunnel, such as the pneumatic air tube system, may represent as one of the candidates for the future goods’ transportation system.

2. Pneumatic air tubes
The pneumatic air tube system uses the pressure difference between end sides of the tube. Such pressure differences are created by a blower pump and the carrier which contains the goods or others can move through it when the air exists on the guideway. Vance and Mattson [2] broadly define it as, a class of transportation system for passengers or freight whereby capsules are propelled through continuous tubes between terminals.
2.1. Pneumatic capsule pipeline transport for Hospitals

A pneumatic air tube transport system is a distributed network of tubes through which carriers of various sizes containing small items are driven by air flow, which may typically be either a point to point or a multipoint system. Newton et al. [3] have conducted the first numerical investigation on the flow of a cylindrical capsule in a pipeline. It was concluded that the velocity of the capsule substantially depends on the diameter ratio of the capsule to the pipe and the average flow velocity.

Point to point pneumatic air tube transport system (see Figure 1) provides two-way transfer via a single continuous tube linking stations. This system is suitable for use in an application that requires a simple operation and a dedicated link between zones, for instance, an operating theater and the pathology department [4].

![Figure 1. Point to point system [4]](image1)

Furthermore, multipoint pneumatic air tube transport system (see Figure 2) provides full intercommunication between all points in the system. In a situation whereby the systems are large and the traffic is heavy, the network may be split into zones. This can allow local transport of carriers in each zone, and transfer to another zone when required. This type of system is commonly used in large hospitals, for example, the pharmacy and pathology departments being in separate zones [4].

![Figure 2. Multipoint system [5]](image2)

Multipoint systems are controlled centrally by a dedicated microprocessor or computer. The process is done in such a way that the controller receives transfer instructions first, carries out continuous monitoring of the system and then provides system status information. Cleaning cycles may be carried out at pre-determined intervals if required, in order to keep the pipework free of dust.

The type of system commonly used in large hospitals is called pneumatic tube systems (PTS). This system allows local transport of carriers (see Figure 3) in each zone, as well as transfer to another zone when required, the departments of pharmacy and pathology being in separate zones as for example. The Hospital ‘Rechts der Isar’ in Munich is a good example of the whole spectrum of medical services supplied by a modern healthcare facility [5].
PTS have been proven to decrease the median turnaround time for potassium and hemoglobin results on specimens from the emergency department by up to 25%. The system that evaluated is a rapid and efficient mechanism for sending specimens to the clinical laboratory which produces no significant influences on analytical results and has the ability to decrease turnaround time [6]. Tanley et al. [7] showed that the Pneumatic Tube Capsule (PTC) tested can be used safely to provide blood bank service to distant patient care areas.

The current allocation of PTS by the Sumetzberger manufacturing of pneumatic tube systems for hospitals, banks, supermarkets, etc. and toll gates as shown in Figure 4. It is a most flexible and the most advanced pneumatic tube system with the best risk management.

Furthermore, it can be indicated that the hospitals have the highest percentage of using the PTS which is 60%, while the industrials have the lowest use of PTS which is 2%. Sumetzberger is a global supplier of pneumatic tube systems were established 1921 and started with pneumatic tube systems in 1961 [8].

2.2. The Pneumatic Mail Tubes

The original idea of PTS must be given to Dennis Papin; he is an engineer presented his paper on the "Double Pneumatic Pump" in 1667. During the year of 1887, the first operational internal facility PTS were installed in the USA at Lynn, Massachusetts. Moreover, a small external PTS were installed between two offices in New York City in 1888 for the Western Union [9].

There was a series of annual reports to the Congress from as early as 1889 through 1891 by the Postmaster General (PMG). These reports, investigate the feasibility of implementing a pneumatic tube system for movement of the mail. In the Act of 13th July 1892, an investigation was authorized by the Congress into the "Rapid Dispatch of Mail by means of Pneumatic Tube" [9].

In 1867 the editor of the Scientific American in the middle 1800s Alfred Ely Beach wanted to build a subway in New York City [10]. Beach studied the early 19th century Danish theory: "the creation of a vacuum in front of an object could produce tremendous atmospheric thrust behind it". Beach also had theories about an underground PTS for mail which picks up and drops off points at lampposts throughout the city. His PTS was considered as the first mail tube in the U.S.A [9].

PTS were also being developed in London, Germany, and Paris. These systems lasted longer than the American systems, but they could not carry much mail because they were only two inches in diameter. However, in Paris, the Carte Pneumatique, which is known as "The Pnue", was mainly used for telegrams and special delivery and it has remained in operation till 1987 with 269 miles of the tube [9].
The first cylindrical carrier to travel through the New York City system (see Figure 5) was one that contained a copy of the Constitution, a Bible, and a flag. The second carrier contained an imitation peach in honor of Senator Chauncy Depew. A third carrier had a black cat in it. Figure 6 shows the capsules used for transferring mails.

According to Aldhous et al. [11] at various times during history, a number of pneumatic systems have existed. One of the current few underground freight systems operating in London is an automated railway run by the Post Office between a number of city centers sorting offices.

The modern pneumatic container transport takes its history from the idea of light and heavy duty “air-mail” from the 18th century, one of the types of capsule tube transport is evacuated tube transport with magnetic levitation train “Maglev” [12, 13, 14] as shown in Figure 7. This system requires an active suspension mechanism. However, it seems reasonable to use an active suspension system that does not create vibrations in the first place as suggested by Jayawant [15].

2.3. Transport cargoes in capsules

There are many researchers have pointed out [16 - 19] the movement of freight within cities is critical to their existence. However, it still remains an issue that is largely overlooked. According to Peggs [20], the first extensive recorded use of pipes for urban transport was by the Romans.

On the other hand, Pneumatic capsule pipeline (PCP) is the method where the air is blown through a pipeline to convey or transport cargoes in moving capsules containers or wheeled vehicles through pipelines [21]. All contemporary PCP systems, such as those used in the former Soviet Union for transporting rock [22], and those used in Japan use wheeled capsules rolling through a pipeline [18]. Modern systems of PCPs, used with great success in Japan [23 - 25] use capsules and pipes (conduits) of either circular or rectangular cross sections as shown in Figure 8.
Moreover, as shown in Figure 8 there are two types of PCP have been developed and used successfully in Japan. It was suggested that, in order for capsules to maintain stability in a round pipe, the capsules have to use gimbaled wheel assemblies as shown in Figure 8 (a). While, for rectangular or square capsules in rectangular or square conduit, the capsules can use ordinary vehicle’s wheels, with four large bottom wheels on the bottom and four small guide wheels on the sides of each capsule, as shown in Figure 8 (b). As shown in Figure 8, in order to reduce the number of trains that must be injected into the pipe, several capsules have to be linked together to form a train [26].

The circular type of PCP, using steel pipe of about 1 m diameter, is currently used by the Sumitomo Company to transport limestone over a distance of 3.2 km [23]. It has been in use since 1980 with great success, achieving an availability record of 95%. The same system has been used for underground transport and disposal of hazardous waste [25].

Finally, a temporary PCP of a long tunnel for bullet trains with a rectangular cross section about 1 m x 1 m was used in Japan (see Figure 9). The system transported premixed concrete into the tunnel and took out the soil and rock out of the tunnel. It had lots of advantages over the use of the truck for tunnel construction [24, 25].

All the PCP systems used in Japan use blowers pump to blow air through the pipes; the moving air, in turn, drives the capsules through the pipe. There are two reasons for the low line fill and low throughput. The first is the use of fans which block the passage of the capsules, the second reason is in line loading/unloading [21]. The ideal within urban freight, such as a system that could transport goods to any location at any moment in time, could set the delivery time accurately and never delayed, and above all, one which does all this without anyone notice [27].

Recently, Belova & Vulf [12] noticed that the material in the pipeline plays an important role when transporting weighting cargoes, and also was done an experiment to get the average coefficient of dynamic friction which is can be used for the further research of PTS. However, Leephakpreeda [28] has done an experiment for a real prototype of an electro-pneumatic system and noted that the traveling time of the capsule depends on upon the mass of the capsule for a given pressure difference between the two ends. The experiment has proved that the theoretical model can be used to calculate different types of the PCP transport. Moreover, Liu & Lenau [29] have been examined different sizes of PCPs for four kinds of applications in a particular area of New York City and they mentioned that the success can lead to future of use PCPs in New York City and other cities in the nation, it is a
significant reduction of trucks on highways, thus reducing traffic jams, accidents, and air pollution. Furthermore, Kosugi et al. [23] showed the applicability of transport pneumatically waste packages and buffer materials between the surface and the underground based on the results of both analytical simulation and experimental study. Also, Asim et al. [30] investigated the various costs involved in a pipeline transporting capsule. They revealed that an increase in the pipeline diameter increases the manufacturing, and operating costs. Moreover, an increase in the pipeline diameter decreases the pressure drop, resulting in more pumping power required for the pipeline, and then Lynam [31] is forced to conclude there are no easy costing methods with varying costs with every option and technology. Van den Kroonenberg [32] has developed a mathematical model for the prediction of the velocity of the cylindrical capsule and the pressure drop within the pipeline.

2.4. The difference between the Japanese PCP systems and the pallet tube PCP

The capsule of the pallet tube system designed for New York City uses steel wheels running on steel rails. This is the main difference from the capsules used in Japan, which use rubber tires. The reasons for choosing such a steel wheels instead of rubber tires are, the steel wheels have a rolling friction coefficient approximately 5 times smaller than the rubber tires, hence greatly reducing friction and saving energy. The capsules with steel wheels in term of control is easier at branching points and in terminals. The wear resistant for steel wheels is more than rubber tires, herewith minimizing wear and maintenance cost; whereas the speed of capsules limited to 15 m/s with rub tires and cannot run at higher without damage caused by heat generated. Furthermore, the capsules using steel wheels can run at much higher speeds without temperature build-up. Using steel wheels has disadvantage instead of rubber tires is that noise is higher. However, this is not a serious disadvantage because of most the generated and dissipated underground, nobody is disturbing. When the capsules are outside the pipe the noise can be heard. The noise of PCP comes from contacts between the wheels and rails. Another main difference between the Japanese PCP systems and the pallet tube PCP system is that the latter must use electromagnetic pumps instead of blowers. This is due to the complex network of conduits and the multiple inlets/outlets required for the latter, which is a system that is more extensive than the current subway system [26].

2.5. Advantages and disadvantages of using the pneumatic capsule pipeline system

Firstly, the advantages of using the system of PCP to transport freight are not difficult to see [21], the PCP has many environmental and safety benefits such as, the high speed from 15 to 20 m/s, ecological safety and the possibility to fully automate, the movement will reduce the trucks on highways, resulting in reduced, accidents traffic jams, air pollution, noise and damage to bridges [1] [21] [12] [13] [29]. The pipeline, which is the major part of the capsule transport system, is maintenance free [1]. The greatest advantage of this system, it can carry large size cargoes with standard containers [21]. The high rate of speed between stations for limited quantities of mail [9]. Freedom from surface congestion [9]. Such a system for hospitals is a rapid, efficient mechanism for sending specimens to the clinical laboratory and has the ability to decrease turnaround time [6]. The optimization model of using spherical capsules for transporting through pipelines has both robust and friendly user [30].

Secondly, the disadvantages of using PCP are the difficulty of design all forms of the pneumatic pipeline [33]. The cargo transportation prices are rising each year [34]. The high cost of creating and maintaining the vacuum tube and the tracking pipeline itself [35], [21] [29]. However, there are special disadvantages of the pneumatic tube mail system which are the inability to carry special delivery parcels due to the size of the carriers and because of that can carry only five pounds of mails in each container. Moreover, the inability to dispatch between intermediate stations during continuous transmission between any two points and to railroad companies without additional handling, also dampness and oil damage to mail Service, interruptions block an entire line, congestion from heavy mail volumes, equipment takes up rented building space, and lastly the excessive costs [9].
3. The magnetic levitation (Maglev)

The conventional train drives forward by using friction between wheels and rails, the magnetic levitation (Maglev) is a modern train which uses electromagnets to levitate on the guideway and produce propulsion force electromechanically without any contact [36].

The Maglev train can be reasonably dated from 1934 when Hermann Kemper of Germany patented it. Last time ago the development of the Maglev train went through the quickening period of the 1960s, the realization of the 1970s to1980s, and the test period of the 1990s, lastly is accomplishing practical public service in 2003 in Shanghai, China [37 - 40].

In terms of levitation, it is worth to know that typically there are three types of levitation technologies; i). Electromagnetic suspension (EMS), ii). Electrodynamic suspension (EDS), and iii). Hybrid electromagnetic suspension (HEMS). For EMS, levitation is accomplished based on the magnetic attraction force between a guideway and electromagnets. This methodology is inherently unstable due to the characteristic of the magnetic circuit [41]. Whereas EMS uses attraction force, EDS uses repulsive force for the levitation [42 - 45]. On the other hand, in the EMS permanent magnets is partly used by an electromagnet in order to reduce the electric power consumption [46 - 48] for HEMS, the Maglev train receives its propulsion force from a linear motor, which is different from a conventional rotary motor. This system does not use the mechanical coupling for its rectilinear movement. As a result, the structure of the system is simpler and robust compared to the system which uses a rotational motor [49 - 51].

4. Conclusion

Considering the Pneumatic Capsule Pipeline (PCP) as described above, it can be concluded that the use of PCP extended for underground freight transportation may offer many environmental and safety benefits. This system will reduce traffic jam, accidents, air pollution, noise pollution and damage to roads and bridges to the existing of the conventional transportation system (road vehicles and railways). In view of PCP construction, it had been proven and successful use in Japan. It is, therefore, a PCP approach besides the magnetic levitation (Maglev) system may represent the best new technology for future transportation, goods, and people for solving the transportation problems in the big cities.

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