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Operational Planning and Design Considerations for Underground Logistics Transportation in Texas

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Abstract: The logistics transportation system is critical to the United States economy. Underground Logistics Transportation (ULT) is a class of automated transportation systems in which vehicles carry freight through pipelines and tunnels between terminals. Being able to use a part of the underground space of existing highways will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs. Underground Logistics Transportation (ULT) could be the answer to make freight transport more sustainable and competitive. Texas highways and railroads are expected to increase by nearly 207% from 2003 to 2030. Truck tonnage will grow by 251%, while rail tonnage is forecasted to increase 118%. The number of trucks carrying NAFTA goods will increase by 263%, and the number of rail units will grow by 195%. This will have a profound impact on the highway and rail systems. The objective of this paper is to present requirements and operational components for three types of ULT lines: standard shipping containers, a standard crate size, and a standard pallet size. This study examines the use of ULT as a mode of underground transportation with the help of three case studies. This research shows that ULT is financially viable, feasible, greener, cost effective, and can become an important part of intermodal freight mobility.

Keywords: underground logistics transportation; underground pipelines; tunneling; operational planning; design

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1. Introduction and Background

All over the world, there is a growing demand for sustainable, reliable infrastructure that can ensure the movement of goods and people [1]. There is a realization over the problems associated with under-maintained, overly utilized surface transportation. In both developing countries and developed countries, congested roadways are causing public safety, business productivity, employment, income, GDP, and global competitiveness issues. Surface transportation causes air pollution, traffic delays, accidents, damage to roadways, more fatal accidents, and noise pollution. All these issues multiply and complicate the long-term goal of sustainable growth of the economy and general prosperity [2,3].

The U.S. 125.8 million households, nearly 7.7 million business establishments, and 90,000 governmental units are all part of an economy that demands the efficient movement of freight. Freight transportation has grown over time with the expansion of the population and economic activity within the United States and with the increasing interdependence of economies across the globe [2]. The U.S. population grew by 5.5 percent between 2010 and 2017, reaching 325.7 million in 2017. Meanwhile, the Texas population grew by 12.5 percent between 2010 and 2017, reaching 28.3 million in 2017 [4]. The median household income, another indicator of economic growth, declined by 5.5 percent nationally between 2000 and 2015 [4].

Although freight moves throughout the United States, the demand for freight transportation is driven primarily by the geographic distribution of the population and economic activity. Both the population and economic activity have grown faster in the south and west than in the northeast and Midwest, but the northeast has the highest economic activity per capita. In 2015, the U.S. transportation system moved a daily average of about 49.3 million tons of freight valued at more than USD 52.5 billion [2].

The annual Top Industry Issues Report from the American Transportation Research Institute surveyed carriers and drivers, and for the second year in a row, the truck driver shortage is a top concern ranking third on the 2018 list [5]. The truck driver shortage in America is not a new problem but one that has become increasingly more concerning. Nearly seventy percent of freight in America is distributed through the trucking industry, and there were not enough drivers to meet the scheduling demand and deliver inventories. This has impacted the costs of produce and packaged goods [6].

The trucking industry has dealt with a driver shortage since 2005. Until recently, the shortage was not concerning, as it has always consistently leveled back out. There was a shortage in 2007–2009 that was attributed to the recession, as driver employment decreased. In 2013, the shortage had leveled back out to around 2.9 million drivers, which is what the industry was seeing in 2003. In 2016, there was another jump in the number of drivers [7]. In 2017, the American Trucking Association predicted the highest level of driver shortage. The 2017–2018 shortage was attributed to the electronic logging device mandate that required more drivers to do the same number of miles that drivers were doing before the logging device, and there were not enough drivers to get the same amount of work done [8].

It is estimated that by 2026, the shortage could increase to 174,000 [6]. The truck driving industry is not an industry that is easy for recruitment, as it usually requires workers to be away from home for long periods and meet high productivity demands [8]. Even with consistent raises in pay to attract qualified drivers, driver retention has become more difficult as the demands on scheduling increase [9].

Freight transportation drives the economy of each country. In this fast and connected competitive world, freight is critical to the importing and exporting industry of the United States (U.S.) and globally. DFW International Airport air cargo is the second largest in the U.S. and plays a vital role in the economic viability of Texas and the U.S. According to the Texas Demographic Center (2020), Texas had a population of 29 million people in 2019, and it is projected to reach 39 million by 2045, an increase of 34 percent [10]. This increase will significantly impact the freight growth in Texas. In 2018, more than 2.2 billion tons of freight—20 tons per household and 12,700 tons per business—passed through Texas and contributed to USD 49 billion in tax revenue (Texas Department of Transportation (TxDOT, 2018)). The state is a hub for transporting various goods through different modes such as trucks, rail, barges, ships, and pipelines. The most prominent transportation mode in Texas is air cargo, and it is increasing at an astronomical speed as per TxDOT [10]. Currently, DFW International Airport is ranked ninth as one of the top airport freights in the U.S. According to DFW records, DFW receives 75,000 tons of cargo on an average monthly basis. Its total air cargo growth between 2016 and 2045 is expected to produce a yield of 1.8 million to 4.2 million, increasing by 129 percent or 2.4 million tons. The DFW International Airport and Fort Worth Alliance Airport were forecasted to transport half of the U.S. airport freight tonnage by 2045 [10].

Consequently, this growth will undoubtedly put pressure on the existing freight [11], causing heavy traffic and truck congestion as they wait in lines at the cargo area, extending onto the roads and parking entrances leading into this area. The heavily busy and congested road traffic presents alarming concerns about public safety, business productivity, economic loss, traffic delays, damage to roadways [12], air pollution, noise pollution [13], accidents, growing accounts of fatal accidents that were contaminating the natural environment, as well as the economy of a country.

Automated goods transport could generate significant efficiency gains, among other things, by reducing the activity's negative social and environmental externalities. This is particularly important for a recovery from the crisis caused by the COVID-19 pandemic that is transformative, sustainable, and in line with the commitments to reduce polluting emissions associated with transport [14].

Underground Logistics Transportation (ULT) is an alternative solution for the above-mentioned problems, and building this new infrastructure will require less space, create less environmental problems, and need fewer drivers. ULT is a class of automated transportation systems in which vehicles carry freight through pipelines and tunnels between terminals, being able to use a part of the underground space of existing highways, which will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs [15]. Also, ULT includes all the methods of automated transport of general cargo by vehicles moving through a network of underground tunnels [16,17].

Freight transportation is a technology to transport most cargoes, normally transported by trucks, including construction materials (i.e., sand, gravel, and cement), goods in pallets and crates, boxes, etc., and even full-sized (i.e., 40 ft length) shipping containers [18]. ULT is not a new concept, and this system has been in operation since 1927 by Royal Mail at the Mail Rail System in London, the UK, to move mail between different areas of London. At present, in Japan, the ULT system is being used successfully to transport bulk materials for Nippon/Daifuku and Sumitomo Electric Industries [19,20].

Additionally, in Georgia, two ULT systems have been implemented to transport crushed rock and in Russia to move garbage bags [21]. One of the key benefits of ULT is being able to build under an available existing highway's right of way, which greatly reduces construction costs. Najafi [15] investigated the feasibility of underground freight transportation, which allows for the optimized use of the existing transportation capacity. The objectives of this project were to evaluate, using three sizes of pallet, crate, and container, underground freight transportation (UFT) in three proposed routes in Texas: specifically, the Port of Houston to the City of Lancaster (near Dallas) for 250 miles, the Port of Houston to a distribution center within 15 miles of the Port's point of origin (Baytown), and the border crossing with Mexico in Laredo for four miles. The whole project was divided into six tasks: planning and design, construction method, cost estimating, environmental impacts, financial aspects, and stakeholder committee; each task was investigated extensively [15].

Youth lacking education credentials and/or work experience struggle to obtain employment in weak labor market conditions. Black youth face a 26% rate of extremely disproportionate institutionalization and criminalization in the United States, partly attributable to dislocations [22]. According to the Organization for Economic Co-operation and Development (OECD), the disconnected youth were young people who were not in employment, education, or training (NEET) but faced unique employment barriers, usually due to the structural and systematic forces of segregation, unstable jobs, and discriminatory hiring practices. Thus, the ULT project has the potential to develop and improve the living conditions of underserved NEET youths. It will increase the number of available jobs for these youth, contributing to increased expenditures to stimulate the economy. Unfortunately, fewer than 10% of disconnected youth were served by federal workforce development programs [22]. This concept also addresses the Smart and Connected Communities' vision of connecting the social community with basic science and technology to enhance the human condition.

The objective of this paper is to present the requirements and operational components for three types of ULT lines: standard shipping containers, a standard crate size, and a standard pallet size. This study examines the use of ULT as a mode of underground transportation with help of three case studies.

2. ULT Application

Miles and Loose [23] conducted a ULT feasibility study for the use of highway M25, London, UK, for Mole Inc. In this research, Miles and Loose studied how the new technology affects direct costs and capital costs as well as the potential social and environmental benefits. Based on this study, by using ULT, the travel time would be reduced by up to 5%, which is equal to an estimated USD 4 billion in cost savings. In addition, based on estimated costs in the UK, truck road-building costs millions of dollars per mile; however, the cost of one mile of ULT depends on the amount of earthwork and boring, which is approximately USD 3 million per mile.

Based on the 2005 statistics of the UK, Heavy Goods Vehicles (HGVs) caused 486 accidents and 3200 serious injuries while carrying 63% of the UK's freight; however, oil pipelines carried 4% of the freight with no injuries. Finally, ULT works with electricity, which can be fed from a renewable source. Therefore, the amount of emitted air pollution is much less than that of trucks. Additionally, trucks have a high visual impact and produce noise pollutants. Nevertheless, Miles and Loose (2008) predicted that all these negative impacts would be reduced by the ULT system [23].

Miles [24] were awarded a grant in 2015 to investigate the feasibility of the application of an urban freight pipeline solution in Northampton, UK. This conference paper derived from this study. The objectives of this study were to investigate the role of freight pipelines in the supply chains of Northampton and provide a comprehensive methodology to examine freight pipelines in any city in the world. They accomplished their objectives in three phases of data gathering, analysis, and the examination of ULT design specifications [24].

Roop [25] investigated freight transportation problems in the ports of entry (POEs) along the border of Mexico from El Paso, TX, to Ciudad Juarez. This region faces heavy traffic congestion due to truck traffic. It is estimated that on average, each truck spends about one hour in peak traffic (most conducive to congestion). The other issue that led to this problem was establishing manufactures in this area, since the U.S. is the closest market for Mexico. These problems contribute to more freight traffic, which causes a significant amount of air pollution, increases fuel consumption, and creates more delays in freight delivery. In addition, a considerably high amount of drug trafficking threatens the security of freight transportation. In order to solve these problems, an alternative freight transportation system, the Freight Shuttle System (FSS), has been suggested [25].

To analyze the feasibility of the FSS using trucks on highways, a 24-year statistical study was conducted. One of the focus areas of this study was air pollution reduction. Since the FSS is operated by electricity, and green electricity generators such as solar and wind turbines can be used, in a 24-year period, 87,000 tons of air pollution, including 696 tons on NOx, could be reduced. In addition to air pollution, the FSS plays a significant role in petroleum consumption by reducing 47.9 million vehicle miles traveled (VMT), which leads to reducing fuel consumption by up to 7.5 million gallons. By calculating truck delay times, the FSS can save approximately 3.1 million hours of delay, which costs USD 102 million dollars. Finally, by utilizing inspect-in-motion technology on the FSS, Customs and Border Protection patrols can inspect 100 percent of cargoes in less time [25].

Mousavipour [26] analyzed the feasibility of underground freight transportation in Texas and identified features and benefits of ULT as well as its limitations compared to other modes of transportation. She supported her research by providing a literature search about the current and future statuses of the U.S. and Texas economies, population, freight transportation, and future needs regarding freight transportation capacity.

In the Netherlands, between 1994 and 2001, different research programs investigated the technical and financial feasibility of Underground Logistics Transportation (ULT) in urban areas as well as the use of ULT at airports, seaports, and industrial areas [27]. At the Delft University of Technology, a test site was in operation until 2001. In 2021, Hardt Hyperloop proposed a hyperloop network for goods between the cities of Amsterdam and Rotterdam in the Netherlands [28].

In Germany, the Ruhr University Bochum conducted research on CargoCap. A 1:2 scale model of Cargo Cap was developed to test the main components of the capsule. 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 and difficult transport solutions can be found aboveground [29].

China has investigated freight capsule pipelines since 2003, for instance, to move containers to and from the ports of Shanghai [30] and to collect waste in Shanghai [31]. Freight traffic in cities and at seaports in China is increasing rapidly and is generating congestion problems and environmental issues. In China, ULT has been included officially in the planning and research for the Beijing Sub-Central District, the Yangtze River Demonstration District, and other new cities and districts [32]. ULT is proposed for different purposes and also in different sizes [27], ranging from small tubes with a diameter of approximately 1.5 meters, medium–larges tubes with a diameter of between 2 and 3 m, to large tubes or tunnels with a diameter of about 5 m. The different systems can be categorized as presented in Table 1.

Table 1. Categorization of systems based on type of cargo and distance (adapted from [33]).

Load Unit Distance	Parcel/Box Size	Pallet Size	Container/Swap Body Size
Short distances (up to few km.)	Roller Conveyor Belt Conveyor AGVs Tube systems	Roller conveyor Belt Conveyor AGVs	AGVs
Medium distance (several tens of km.)	Tube systems	AGVs Automated truck (Dual-Mode Truck) Capsule systems	AGVs Autom. Trucks /MTS Autom. Trains
Long distance (several hundreds of km.)		Capsule systems	Autom. Trucks/MTS Autom. trains Large capsule systems

3. ULT Construction Technology

According to [34], most large cities in the world, such as New York and Tokyo, have severe traffic congestion problems on the streets and highways. Such cities can benefit greatly from an underground network of pneumatic capsule pipelines (PCPs) to transport freight. The purpose of this project is to gain an understanding of the approximate cost of constructing such underground PCPs under different conditions.

The cost study is focused on a PCP system for transporting entire containers such as those carried by trucks. In urban areas, the study assumes that the tunneling is through underground bedrock approximately 10 m deep. The condition is similar to that in New York City and many other major cities around the world. Deep underground tunnels require the use of a 15 ft diameter tunnel bored using a modern TBM. A lining with shotcrete is to be provided for the tunnel case. Additionally, the tunnel cost includes a flat floor for the rail base of 9 ft width. For rural areas, the PCP system for such a purpose can be built most economically by using a reinforced concrete rectangular conduit of a 9 ft width and 11 ft height, with a standard railroad track on its bottom, which add to the inner dimensions; a minimum of 1 ft of reinforced concrete for the walls, ceiling, and floor needs to be included.

According to this study, to shorten the construction duration of rural PCP construction, a prestressed concrete cylinder pipe (PCCP) is considered as an alternative to concrete conduit, which should significantly lower the labor and equipment costs but increase the material cost. As a result, the cost of tunneling is about six times is higher than an open cut, at USD 9200 per foot and USD 1425 per foot, respectively. With a PCCP, the cost of open cut increases to USD 5000 but is still more cost effective than tunneling method. These costs vary depending on the structure type, construction method, construction materials, soil and rock conditions, groundwater level, location, and costs of labor and electricity [35].

Rezaei [36] identified construction technologies for building a large diameter tunnel and showed several important parameters to decide on a proper construction method for building a ULT system. To accomplish this research, first, she discussed all different types of tunneling as well as their advantages and limitations for large diameter pipes to implement ULT. Then, based on previous case studies, designs, and constructions of different ULT concepts, such as the GRID Logistics concept, Cargocap, and the ULT concept at CUIRE, these were compared.

Tabesh [13] presented major parameters that need to be considered when comparing cut-and-cover with trenchless methods to select the most appropriate method. As a case study, the authors present the feasibility of using cut and cover and tunneling to build a ULT system from the Port of Houston to Dallas by providing an analysis of applicability, constructability, and cost to select the appropriate method. This paper describes schematic designs and operational parameters for a ULT system for three types of loads: standard shipping containers, crates, and pallets. The design components include the tunnel system, the vehicles, the conveyance system (tracks and power systems), the access and ventilation shafts, and the terminal design and intermodal load-transfer systems. Separate conveyance systems were proposed for each load type. The freight lines were proposed to be located under the existing roadway right of way (ROW), including the space below the highway cross-section, namely below medians, shoulders, aprons, and frontage roads when applicable. Potential long-haul and short-haul routes for ULT systems were also proposed.

With the help of case studies, operational components such as operating speeds, headways, line capacities, and the associated fleet sizes, number of forklifts and handlers, maximum vehicle loads, and power system requirements were addressed. Finally, three potential routes were proposed. These include a line between the Port of Houston and the City of Dallas near Lancaster, a line from the World Trade Bridge at Laredo, TX, crossing the border to an inland terminal north of the border, and a third line between the Port of Houston and an inland satellite distribution center.

4. Methodology

This paper discusses the schematic designs for standard shipping containers (8.0 ft by 9.5 ft by 40 ft), crates (5 ft by 5.3 ft by 10.4 ft), and pallets (3.3 ft by 3.3 ft by 4 ft). The design components include the conduit system, the vehicles (capsules), the conveyance system (tracks), the access shafts, and the terminal design and intermodal load-transfer systems. This task also covers the ULT operational parameters. Equations were developed to estimate the required headways, number of vehicles, and loading/unloading handlers/forklifts as a function of the freight transportation demand. For the propulsion system, the linear induction motors (LIMs) and automation technologies provide effective means of transporting all freight sizes, including standard shipping containers ([15] also available at: https://texashistory.unt.edu/ark:/67531/metapth902975/m1/77/, accessed on 15 July 2024).

5. System Components

To gain a better understanding of system components and feasible design alternatives, the literature on previous tubular freight lines, either proposed as a concept or constructed as a demonstration project or operational on a limited basis, were examined. The Federal Highway Administration (FHWA) conducted a study with assistance from Volpe, Volpe's National Transportation Systems Center, and others [37,38]. Attention to major innovations in transportation was taken into consideration. These include the Sydney Freight Circle for container transport from the Port of Sydney to seven distribution warehouses [39], the container port expansion project in Shanghai [32], and any currently operating systems in the mining industry [39,40]. In addition, proposed systems such as a New York Port Authority ULT line proposed by [35] and the Freight Shuttle System proposed by [25] were also examined. These studies, along with input from project stakeholders, formed the basis for the schematic designs of various elements of the ULT system. This includes the vehicle and tunnel design, the track design, the propulsion and power system designs, and the terminal design as well as the short- and long-haul potential routes. The subsequent sections provide more details.

6. Design of Tunnels and Vehicles: Case Study of Texas

6.1. Freight Sizes and Dimensions

In the design of the tunnels and vehicles, three freight sizes were considered. The largest freight size was the standard shipping container [15], which is 8 ft wide, 9.5 ft high, and 40 ft long (8 ft W × 9.5 ft H × 40 ft L) with a maximum gross weight of 68,000 lbs. For the sake of consistency, this study retains the width, height, and length order of dimensions throughout. Note that the United Parcel Service (UPS) and Federal Express (FedEx) use length, width, and height in that order to calculate the weight and cubic size of all their packages. An intermediate freight size considered was an International Air Transport Association (IATA) Type 6 standard crate (LD-11 crate), which is 5 ft W × 5.3 ft H × 10.4 ft L with a maximum gross weight of 7000 lbs. Finally, the smallest size freight considered was a standard U.S. pallet size: 3.3 ft W × 3.3 ft H × 4 ft L with a maximum gross weight of 4600 lbs [15].

6.2. Tunnel Types and Dimensions

For each freight size, two types of pipelines and tunnels, both cylindrical and rectangular, were envisioned. Cylindrical tunnels (pneumatic tubes or concrete pipes) were found to be more suitable where tunnel boring machines (TBMs) were considered, such as in urban/suburban areas. For this application, tunnels can be as deep as 50 ft depending on soil conditions and the presence of other underground installations such as buried utility lines.

The internal diameters of pipelines for a single-track system were 14 ft for shipping containers, 10 ft for crates, and 7 ft for pallets. The tunnel wall thicknesses were 1.0 ft, 0.9 ft, and 0.7 ft, respectively, making the tunnel external diameters 19 ft, 11.8 ft, and 8.4 ft, respectively. In twin-track tunnels, considerably larger diameters were required, namely internal tunnel diameters of 23 ft, 15 ft, and 11 ft for containers, crates, and pallets, respectively. The tunnel wall thicknesses would be 1.5 ft, 1.2 ft, and 1 ft, respectively.

Rectangular tunnels (box culverts) and precast circular concrete pipes were used for cut-and-cover applications. Within the highway right of way, cut-and-cover applications were practical when adequate space was available under medians or side aprons or where infrequent roadways cross under the right of way. This ideal situation is typically found only in very rural areas. Typical construction entails digging a trench, placing the box culvert or precast circular concrete pipe, and covering to a minimum depth of 5 ft from the top of the box culvert to the ground. Stronger materials than locally excavated soils, such as flowable fills or controlled low-strength materials (CLSMs), were typically used.

The external dimensions for rectangular tunnels were 6.2 ft W × 6.5 ft H × 12 ft L for pallets and 7.6 ft W × 8.6 ft H × 25 ft L for crates. The standard shipping containers would require external tunnel dimensions of 10 ft W × 11.5 ft H × 42 ft L. The tunnel dimensions were independent of the construction materials and local geology. Although typical dimensions for rectangular tunnels were discussed, we anticipated that tunnels for the ULT system were cylindrical. This is to accommodate the tunnel boring machines, which are utilized in the majority of projects to minimize disruption to overland traffic and to communities near the right of way and to avoid adverse environmental impacts. This tunneling method minimizes space requirements and soil excavation [15].

6.3. Vehicle Types and Dimensions

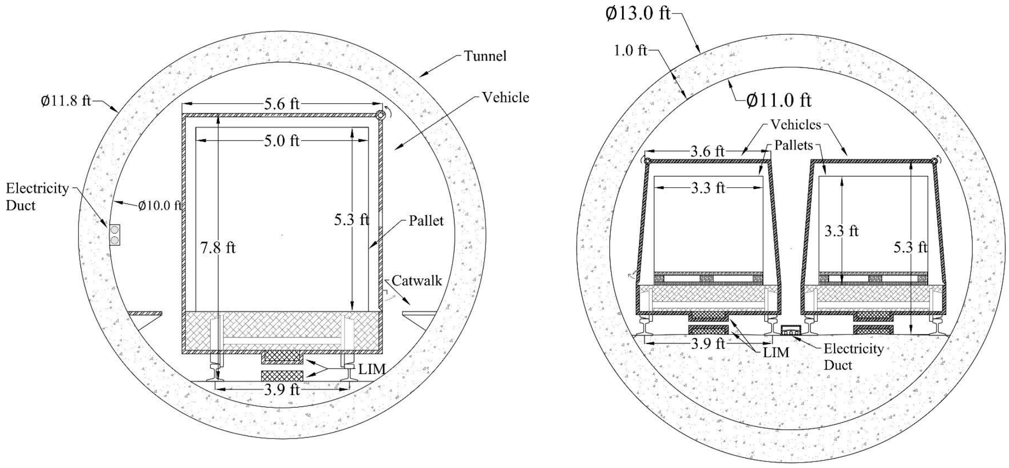
Metal vehicles were designed for the easy placement or retrieval of freight. Closed vehicles were recommended for crates and pallets to prevent load spillage as well as to provide climate control in cases where such provisions were needed (e.g., transport of medicines or perishable foods). Since linear induction motors (LIMs) were proposed in this project to propel the vehicles, an aluminum exterior (good conductor) and steel interior (ferromagnetic) were recommended. These vehicles were rectangular, and their dimensions for pallet loads, and crate loads were 4.2 ft W × 4.5 ft H × 10 ft L and 5.6 ft W × 6.8 ft H × 22 ft L, respectively.

Covered vehicles were not recommended for the standard shipping containers, as there is little chance of load spillage in closed shipping containers. Also, containers themselves can be climate-controlled if needed. Therefore, an open flat-bed vehicle design with a rectangular cross-section is recommended for shipping containers. Extra space in the tunnel is required for utilities, walkways, maintenance, and the aerodynamics of moving vehicles. The suggested vehicle dimensions were 9 ft wide, 10.5 ft deep, and 49 ft long with 3 ft high walls. Containers were placed or retrieved from the top. As in the case of crate and pallet vehicles, an aluminum exterior and steel interior were recommended for these vehicles as well. The aluminum exterior is required for LIM installation and operation.

Table 2 summarizes the types of loads (pallets, crates, and shipping containers), their typical dimensions, and the corresponding tunnel and vehicle types and dimensions. For the reasons discussed above, only circular (single-track and twin-track) tunnels were considered for each load type. This resulted in six types of design combinations. Schematic drawings along with the corresponding dimensions are provided in Figure 1. These figures show other details such as the locations of catwalks and utilities, the dimensions of wheels and tracks, and the locations of linear induction motor's primary and secondary power lines [15].

Table 2. Dimensions of freight types and their respective tunnels and vehicles [15].

Freight Type	Tunnel	Vehicle
	Two single-track tunnels	
	Internal diameter: 7 ft	
Pallets (3.3 ft W × 3.3 ft H × 4 ft L)	Wall thickness: 0.7 ft External diameter: 8.4 ft	Rectangular external dimensions: 4.2 ft W × 4.5 ft H × 10 ft L
	One twin-track tunnel Internal diameter: 11 ft	
	Wall thickness: 1 ft	
	External diameter: 13 ft	
	Two single-track tunnels	
	Internal diameter: 10 ft	
Crates (5 ft W × 5.3 ft H × 10.4 ft L)	Wall thickness: 0.9 ft External diameter: 11.8 ft	Rectangular external dimensions: 5.6 ft W × 6.8 ft H × 22 ft L
	One twin-track tunnel Internal diameter: 15 ft	
	Wall thickness: 1.2 ft	
	External diameter: 17.4 ft	
	Two single-track tunnels	
	Internal diameter: 14 ft	
Shipping containers (8 ft W × 9.5 ft H × 40 ft L)	Wall thickness: 1.0 ft External diameter: 16.0 ft	Rectangular external dimensions: 9 ft W × 10.5 ft H × 49 ft L
	One twin-track tunnel Internal diameter: 22 ft	
	Wall thickness: 1.5 ft	
	External diameter: 25 ft	



(**a**) (**b**)

Figure 1. (**a**) A single-track system for standard shipping containers. (**b**) One twin-track system for standard-sized pallets.

6.4. Potential Proposed Routes

Figure 2 illustrates the locations of the three proposed ULT routes. A potential route considered for shipping containers is a 250-mile ULT route from the Port of Houston (Barbour's Cut Terminal) to the Dallas Logistic Hub south of Dallas in the suburban town of Lancaster. This ULT route can be constructed under the existing rights-of-way of SH-225 and IH-610 in Houston and IH-45 from Houston to Dallas.

Figure 2. Locations of three proposed ULT routes [15].

Another suggested route considered for shipping containers is a short-haul ULT line at the border between the U.S. and Mexico in Laredo, TX. This route is approximately four miles from the Mexican side of the World Trade Bridge in Nuevo to the interchange of the TX-20 Loop and IH-35 near the Union Pacific Railroad Port in Webb County near Laredo.

The World Trade Bridge, one of the four international crossings in Laredo, is the one that handles most of the truck traffic at the Laredo border between the U.S. and Mexico. There is considerable truck congestion at this border crossing, mostly due to customs inspection. While a ULT line across the border would not necessarily reduce the customs inspection delays, trucks could unload their containers onto the ULT line, and containers could be picked up on the other side. This would mitigate the problem of fully loaded trucks idling for hours in queue for customs inspections. In addition, if trucks from Mexico unload their containers onto the ULT line to be picked up at the other end by U.S. licensed trucks, it could reduce the instances of heavy Mexican trucks with potential safety issues traveling on U.S. highways. New customs facilities would need to be constructed to inspect the containers placed onto or coming out of the ULT line before transferring the containers to trucks and rail. These facilities could be placed away from the mainstream traffic line with truck parking available. Existing customs facilities would remain operational to handle non-commercial traffic as well as commercial trucks, which either opt out of or are not allowed to use the UFT system due to a particular payload they might be carrying or for any other reasons.

Another short-haul ULT route is considered from the Port of Houston (Barbour's Cut Terminal) to an inland satellite port immediately outside the Houston metropolitan area. One possible inland port location would be in Baytown, TX, where IH-10 crosses SH-146. This location is approximately 15 miles northeast of the Barbour's Cut Port, with a large existing truck terminal on IH-10. It is also near a major Chevron petrochemical facility.

The above ULT route could handle certain types of freight such as perishable foods that should not undergo excessive delays or hazardous freight that should not be carried in densely-populated areas. This route was initially designed to handle shipping containers, but, if need be, the system could be downsized to accommodate crates or pallets as well. This system would also have the benefits of reducing truck congestion at the port as well as truck traffic on city streets and highways. If this route proves to be feasible, several such inland satellite distribution centers could be established under major freeway corridors on the eastern, western, and northern boundaries of the city. Table 3 presents all three routes with the freight types and lengths.

Table 3. Route information with freight types and lengths.

No	Route	Freight Type	Origin	Destination	Length (Mile)
1	Dallas–Houston	Shipping container	West side of Barbour's Cut Port, Houston	Dallas Logistic Hub, north of Union Pacific Intermodal Terminal, Lancaster	250
2	Laredo Border	Shipping container	Southwest of the World Trade Bridge, Nuevo Laredo, Mexico	Intersection of IH-35 and US 59, north side of Union Pacific Intermodal Terminal, Laredo	4
3a	Houston Port–Satellite Dist. Center	Shipping container	West side of Barbour's Cut Port, Houston	Truck terminal on northeast side of IH-10 and SH 146, Houston	15
3b	Houston Port–Satellite Dist. Center	Crate	West side of Barbour's Cut Port, Houston	Truck terminal on northeast side of IH-10 and SH 146, Houston	15
3c	Houston Port–Satellite Dist. Center	Pallet	West side of Barbour's Cut Port, Houston	Truck terminal on northeast side of IH-10 and SH 146, Houston	15

6.5. Typical Highway Cross Section

The main idea in using an underground system for transferring goods is to use the current technology to bore tunnels under existing highway rights of way in order to enhance corridor capacity, reduce traffic congestion, improve safety, and mitigate the environmental impact. To design such a ULT system, it is necessary to identify various cross-sectional elements and dimensions to determine unused or available spaces within existing rights of way that could be utilized to construct such systems. All three proposed ULT lines were beneath major highways owned by TxDOT with by-and-large similar cross-sectional elements and geometric characteristics. Route 1 (the Port of Houston to City of Lancaster) is proposed to be located below the IH-45 right of way, Route 2 (the Laredo Border route), which is partially below the TX-20 Loop, and IH-35 to Route 3 (the Port of Houston to inland satellite port) is below the TX-201 Loop.

The highway elements in each corridor include medians, main lanes (including shoulders), aprons (area between main lanes and frontage roads), frontage roads (including shoulders), and side slopes (area from the frontage road boundary to the right-of-way limit). At times, in urban areas, the median may be very narrow or even non-existent due to a limited right of way. In some other areas, there may be no frontage roads, in which case the side slopes will start from the outside edges of the main lanes to the right-of-way limits.

The UFT project is designed to be constructed beneath the existing rights of way. With the exception of any land required for terminals, there will be no need for right-of-way purchases. To ensure this, identifying the detailed right-of-way elements and associated widths for each segment within each corridor is necessary. The width of each highway cross-sectional element is derived from TxDOT GIS databases.

6.6. GIS Databases and Maps

The geographical information system (GIS) has the ability of editing, storing, analyzing and displaying geospatial data. It can also provide comprehensive information about the project environment and specifications. GIS data may include descriptive information on spatial data and a database that is geographically searchable. For large-scale projects such as ULT, the GIS is an efficient tool to manage and analyze data on cross-sectional elements within the right of way for each corridor segment.

For the operational planning and design of the system, the GIS is utilized to characterize the geometric elements of the highways in each of the three ULT corridors. Other physical elements, including obstructions (e.g., creeks, rivers, underground structures, etc.), bridges, pipelines, and intersecting roadways, were also included in each GIS database. The data were arranged within a one-mile distance from origin (DFO), which is a common method for analysis in long corridors, such as those in this project. In this method, the specifications for each one-mile highway segment have been classified into one record and were numbered based on the distance of the segment from the beginning of the project.

For the three main corridors proposed in the ULT project, attempts were made to maintain consistency in building the database for each corridor despite the differences encountered in the availability and format of the data from one corridor to the next. The TxDOT GIS database discussed earlier was the main source of data for this purpose.

6.6.1. Route 1: Port of Houston to the City of Lancaster (Near Dallas)

This route is about 250 miles long and starts in Barbour's Cut Port terminal in Houston and ends at the Lancaster Intermodal Terminal south of Dallas. The route is mostly designed to be under the IH-45 corridor except in the Houston urban area, where it is under TX-225 and IH-610.

6.6.2. Route 2: Laredo Border

The Laredo Border route starts from the southwest end of the World Trade Bridge in Nuevo Laredo, Mexico, and terminates at the intersection of IH-35 and the Tx-20 Loop on the north side of the Union Pacific Intermodal Terminal. The route is four miles long, with less than one mile located on the Mexican side of the border.

6.6.3. Route 3: Port of Houston to Inland Satellite Distribution Center in Baytown

To decrease the truck traffic in the port area as well as on more congested urban roads, a ULT route is designed to transfer freight between the Port of Houston and an inland satellite distribution center, which trucks can more easily access to pick up or unload containers. One end of this route is at the west side of the Barbour's Cut Terminal, and the other end is at a truck terminal on the northeast corner of the IH-10 and SH-146 interchange. This route is 15 miles long and is located mostly below the TX-201 Loop.

7. Estimating Operational Parameters for the Shipping Container System

A component of the operational design of the system is to develop a relation between headway, flow, and speed for the ULT system. The findings can then be applied to the proposed ULT lines between Houston and Dallas and between the Laredo border and Houston to distribution center routes. The goal is to determine the number of handlers required at the terminus points as well as the desired container flows per day, the number of vehicles needed in the system, the operating speed, and the minimum safe headway.

Variables that significantly impact the operation of a ULT system include the operating headway, loading/unloading operation, operating speed, and the route length. While a small headway may raise safety concerns, a large headway will decrease the system efficiency. The capacity in a ULT system in terms of the containers transported per day or per unit time (container flow) should be sufficiently high to justify the construction and operation of the ULT system.

Speed has a close relation to flow and headway. The overall operating speed should be comparable to that in other modes of freight transportation, such as trucks and trains. Speed is an important factor in energy consumption (power requirements). The above operational characteristics (speed, flow, and headway) strongly influence the ULT terminal design system, such as the number and performance characteristics of handlers available for loading and unloading, the number of loading/unloading platforms, and the land area required for a terminal. The following sections elaborate on the relationship among headway, flow, and the number of handlers and vehicles (Najafi et al., 2016).

8. Operating Speed in the ULT System

As stated previously, the proposed ULT system will use electric linear induction motors (LIMs) for its propulsion system. As is the case with other sources of energy, the energy consumption in LIM systems has a direct relation to the operating speeds and acceleration rates. Keeping the operating speed of the ULT system low will lead to lower power requirements and operating costs. A lower speed also has benefits regarding the wear and tear on rail tracks, vehicles, the overall tunnel system, and, therefore, system depreciation. Based on the above, an operating speed of 45 mph is considered optimum speed for the Port of Houston–Dallas ULT system. This speed is high enough to be comparable to the overall speeds of trucks and freight trains but low enough to minimize energy consumption. The fact that the route will be unhindered by underground traffic and stop lights will assure a timely delivery.

According to the Federal Highway Administration (FHWA), the average truck speed on IH-45 between Houston and Dallas is about 54 mph. The proposed 45 mph ULT speed, however, can be competitive with truck speeds considering that the 54 mph speed is the average operating speed for trucks and does not account for refueling stops, driver breaks, being checked at weigh stations, etc. Therefore, the average overall truck speeds were expected to be considerably lower than 54 mph.

Moreover, the freight rail system connecting Houston to the DFW metropolitan is a part of the Union Pacific Railroad Company. The average speed in this system is 30 to 33 mph, which is lower than the designated 45 mph speed of the UFT system. A comparison of these data indicates that the optimum speed for the ULT system is about 45 mph, which is comparable to or higher than truck or rail operating speeds yet low enough for optimum power requirements.

9. Estimating Minimum Headways

Several factors influence the choice of headways in the ULT system. Two types of ULT headways can be defined: the minimum headway and the operating headway. Safety concerns and propulsion system restrictions provide the basis for determining the minimum headway. Operating headway, on the other hand, is defined based on the desired system flow, which could be lower than the system capacity.

The minimum headway (h_{min}) can be determined so that it meets the propulsion system requirements and prevents collisions between successive vehicles. This suggests that the headway between two successive vehicles should be large enough for the first vehicle to reach the highest operating speed while providing enough time for the second vehicle to stop safely. The time required to travel the length of a vehicle can be considered in this computation. The functional relation for the required minimum headway based on the above considerations is as follows:

$$h_{min} = \frac{l}{1.47} + 1.47\left(\frac{v}{a} + \frac{v}{d}\right) \quad (1)$$

where the following are true:

h_{min} = minimum headway between vehicles (sec);
l = length of the vehicle (ft);
v = running speed (mph);
a = acceleration rate (ft/sec^2);
d = deceleration rate (ft/sec^2).

The coefficient 1.47 is used to convert the speed from mph to ft/sec.

Regarding the shipping container system, the vehicles should be long enough to accommodate the 40-foot standard shipping containers. With additional front and rear overhangs required for operational purposes, a minimum overall vehicle length of 49 ft will result. Similar to the operating speed, the acceleration rate is also an important variable in energy consumption. A high acceleration rate will increase energy consumption, in most cases without a commensurate operational benefit. An acceleration rate of about 10 ft/sec^2 is recommended for the ULT system, as it is small enough to reduce energy consumption and to prevent containers from shifting yet large enough to minimize headways.

While energy consumption is not a major consideration in the deceleration case, having a high deceleration rate may also result in the shifting of containers or excessive shear force on the vehicle chassis and axles. A deceleration rate of about 10 ft/sec^2 is considered to be a reasonable value in this case, comparable to a rate at which a vehicle is normally brought to stop at a traffic signal. Considering an operating speed of 45 mph, acceleration and deceleration values of 10 ft/sec^2, and a vehicle length of 49 ft, Equation (1) yields a minimum safe headway of about 14 s.

The LIM system imposes limitations on the design and operation of the ULT system. Decreasing the headway between vehicles, for example, could overheat the LIM system. A sufficiently long gap between successive vehicles is needed to give the LIM system time to cool down and to sustain normal operations. Overheating the LIM system is both unsafe and energy consuming. According to the LIM experts consulted, a 30-s headway is an optimum headway for a ULT system for standard shipping containers. By the same token, the optimum headway for both the crate and pallet ULT systems has been set to 20 s (Figure 3).

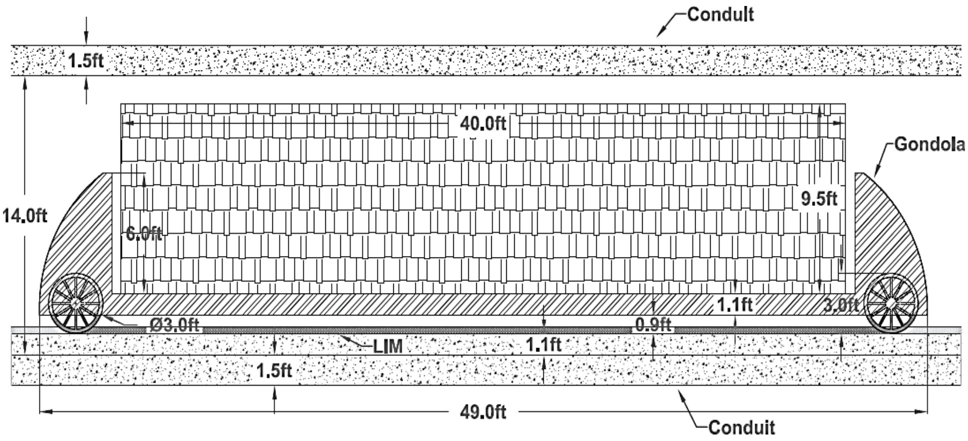


Figure 3. Longitudinal section of a shipping container vehicle (Najafi et al., 2016).

10. Determination of System Capacity

The system capacity is defined as the maximum number of freight loads the ULT system can deliver in a 24-hour day. The capacity can also be considered as the maximum flow of vehicles. Based on this definition, the system capacity is directly affected by the minimum headway of the system. A ULT system with a lower headway will naturally have a higher freight transport capacity. Equation (2) shows the relation between the minimum headway, working hours per day, and the system capacity:

$$C = 3600 \frac{T}{h_{min}} \quad (2)$$

where h_{min} = minimum design headway (sec), T = the working hours (hrs/day), and C = the system capacity (vehicles/day/direction). Based on the estimated minimum headway of the shipping container system (30 s) and a 24-hour workday, the system capacity is estimated to be 2880 vehicles/day/direction.

11. Calculating Operating Headways

The operating headway for the ULT system is primarily influenced by the system flow, the number of containers to be delivered in a day, and the working hours per day at the origin and destination. The operating headway can be calculated using Equation (3):

$$H_{opr} = 3600 \frac{T}{Q} \quad (3)$$

where:

H_{opr} = operating headway (sec), T = the working hours (h/day), and Q = system flow (vehicles/day).

Since the ULT system is designed to operate 24 h a day, Table 4 and Figure 4 show the operating headway versus the container (vehicle) flow in the system.

Table 4. Relation between desired flow rates (Q) and operating headways (H_{opr}) (Najafi et al., 2016).

Q (Containers/Day)	h (Sec)
1500	58
2000	43
2500	35
3000	29
3500	25
4000	22

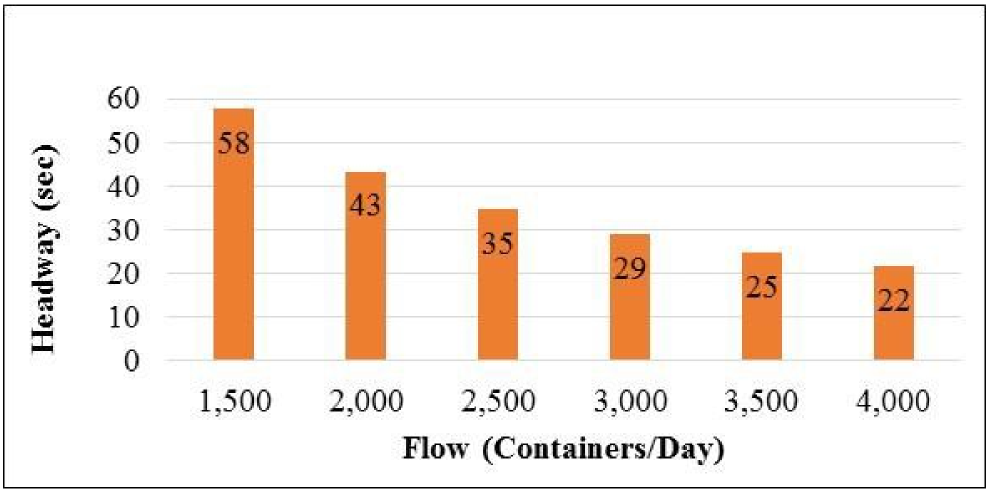


Figure 4. UFT system headway vs. shipping container flow [15].

12. Estimating Number of Handlers at Terminals

Handlers were one of the most essential and costly components of a ULT terminal. Handlers were used for both loading and unloading the shipping containers as well as for stacking the shipping containers in the stacking yard and for loading/unloading trucks. The operating characteristics of handlers were significantly influenced by the ULT system headways and capacity. The time required for handlers to load or unload a shipping container determines the number of platforms in each loading/unloading section of the terminal. A ULT system with a lower headway requires a higher number of handlers to accommodate freight arriving or departing.

Equation (4) shows the relation between flow, ULT system working hours per day, the loading/unloading time, and the number of loading and unloading pair platforms:

$$N_c = \frac{Q \times t}{3600T} \tag{4}$$

where Nc = number of loading/unloading pair platforms, t = the loading/unloading time (sec), T = the working hours (h/day), and Q = system flow (vehicles/day).

This number (Nc) is equal to the number of platforms needed in each loading and unloading section of terminal. If we denote Nt to be the total number of handlers required in the system, then Nt = 2Nc. A number of additional (backup) handlers will also be needed in case of emergencies or the breakdown of the operating handlers. It is reasonable to consider two additional handlers for each section of the terminal (loading and unloading sides) as backups. As a result, the total number of handlers required in the ULT terminal can be calculated as follows (Equation (5)):

$$N_t = 2 \times (N_c + 1) \tag{5}$$

where Nc = the number of loading and unloading paired platforms, and Nt = the total number of handlers/forklifts required.

It can be concluded that in a shipping container terminal, assuming 90 s as the average loading/unloading time of a handler, a total of 20 handlers will be needed to handle a capacity of 2880 containers per 24-hour workday. Table 5 and Figure 5 show how the total number of handlers varies with the desired ULT flow.

Table 5. Relation between desired flow rates and the total number of handlers [15].

Quantity (Container Loads Per Day)	Nc, Loading/Unloading Paired Platforms	Nt, Handlers and Forklifts
1500	2	6
2000	3	8
2500	3	8
3000	4	10
3500	4	10
4000	5	12

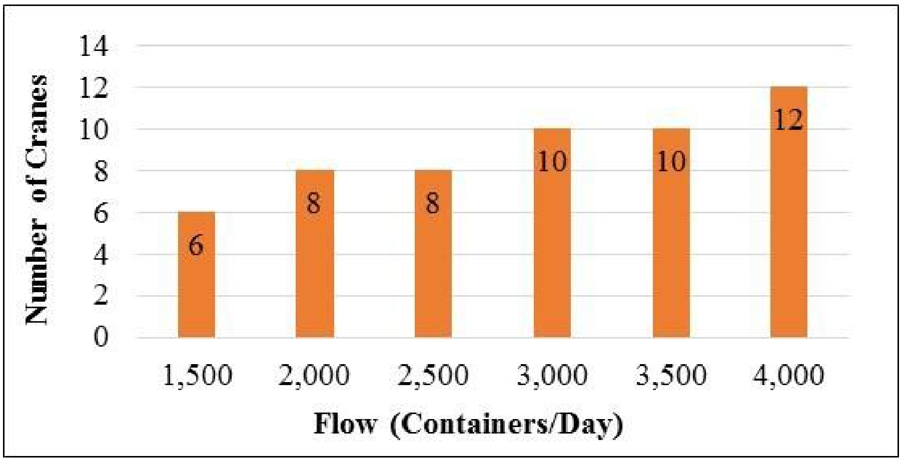


Figure 5. Total number of handlers in relation to system flow [15].

13. Required Number of Vehicles

In the operation of the ULT system, it is necessary to know the number of vehicles in use when the system is operating at capacity (at minimum headway). When the ULT system is handling flows lower than capacity, then not all vehicles will be in use. The excess vehicles can be either on stand-by in each terminal's layover section or continue to circulate in the line with no payload. The required number of vehicles depends on the system length, speed, and operational headway, as follows (Equation (6)):

$$N_g = 7200\left[\frac{L}{v \times h_0}\right] + 1 \cdot 47\left(\frac{v}{h_0}\right)\left(\frac{\perp}{a} \quad \frac{+\perp}{d}\right) \tag{6}$$

where Ng = the number of vehicles in use, h_{opr} = the operating headway (sec), L = the total length of the line (miles), and v = the running speed (mph). Table 6 and Figure 6 show how the number of vehicles required in the ULT system varies with operating headway.

Table 6. Relation between operating headway and number of vehicles [15].

h_{opr} (Operating Headway in Seconds)	Ng (Number of Vehicles in Use)
15	2668
20	2001
25	1601
30	1334
35	1143

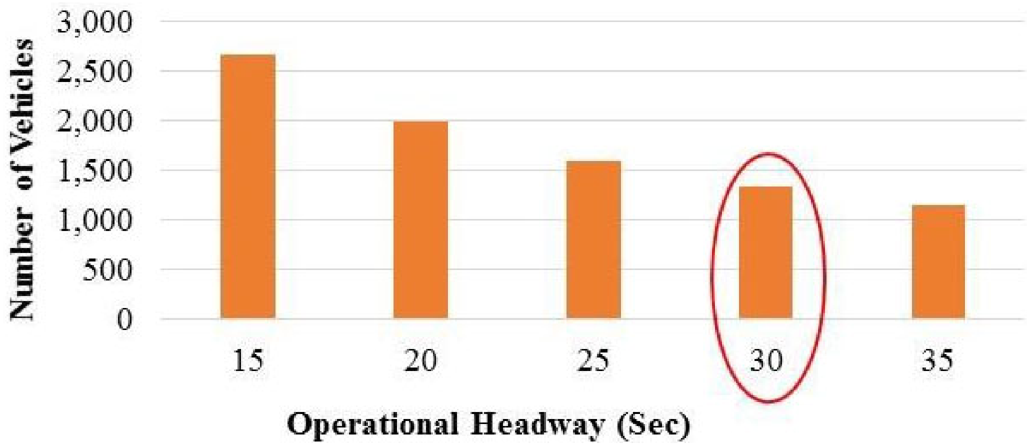


Figure 6. Total number of vehicles in the shipping container system based on the operating headway [15].

14. Headway

Headway is the time gap between launching two successive ULT vehicles. Equation (6) yields the required number of vehicles in the UFT system when the flow in both directions is the same. The minimum headway for the Port of Houston–Dallas UFT system is determined to be 30 s with a one-way line length of 250 miles; hence, a total of 1334 vehicles will be needed for this system.

For the Laredo border UFT line with the container-sized shipping system, the minimum headway remains the same, but its one-way length is only four miles. Thus, the required number of vehicles for this system will be 22. For the line from the Port of Houston to a satellite in-land terminal in Baytown, for a one-way length of 15 miles, a total of 80 vehicles will be required under capacity conditions. Note that this line is being designed for crate- or pallet-load systems. The operating parameters of those systems were analyzed in the next section.

The operating parameters for each of the three routes for standard shipping container systems are summarized in Table 7. As shown, the operating parameters were based on a 30-s minimum operating headway or capacity flow of 5760 containers per day. If the container volume is less than the line capacity, excess vehicles could be stored in the lay-over sections of each end terminal, thus allowing for higher-than-minimum operating headways. Alternatively, as discussed earlier, 30-s headways could continue to be maintained by allowing some vehicles to circulate empty.

Table 7. Summary of operating parameters for UFT routes for shipping containers [15].

Route	Dallas–Houston	Laredo Border	Houston–Dist. Center
Length (miles)	250	4	14
Speed (mph)	45	45	45
Min. headway (sec)	30	30	30
Capacity (vehicles/day)	5760	5760	5760
Handlers (per terminal)	8	8	8

15. Estimating Operating Parameters for Pallet and Crate Systems

15.1. Speed, Headway, and Capacity

As previously described, the 45 mph speed is considered an optimum speed for the UFT system; hence, the crate and pallet systems were designed for a speed of 45 mph as well. Considering this speed and the length of each vehicle, the minimum safe headway can be calculated using Equation (1). The acceleration and deceleration rates were considered to be 10 ft/s^2. Our calculations show that the minimum safe headway for both systems is about 14 s.

Regarding the minimum operating headway, it should be noted that for vehicles carrying crates or pallets, due to lighter gross weights than shipping container vehicles, the minimum headways based on the LIM system requirements were 15 and 10 s, respectively. However, due to safety and handler operating constraints at the terminals, a minimum operational headway of 20 s is recommended for the latter two UFT systems. Knowing the minimum headway, Equation (2) determines the system capacity. For the crate and pallet systems with 20-s headways, the capacity will be 4320 vehicles per day per direction.

15.2. Number of Forklifts

Each vehicle with crates or pallets contains two loads. So, it is reasonable to consider a loading/unloading time that is greater than that for shipping containers. It should be noted, however, that forklifts can be operated faster than the handlers used for shipping containers. But since each vehicle contains two loads, for the calculation of the capacity, the loading/unloading time for each vehicle is considered to be approximately 1.5 times greater than that for shipping containers, i.e., about 120 s per vehicle.

Equation (4) determines the number of platform pairs in a terminal design, which is six loading and unloading platforms for pallet- and crate-sized systems with minimum headways of 20 s and operating at full capacity. The total number of forklifts needed in each terminal is twice the number of loading/unloading platform pairs plus two for backup. Hence, a total of 14 forklifts are needed in each terminal for crate/pallet-sized systems.

15.3. Number of Vehicles

The length of the Houston–Satellite distribution center route, for which the pallet- and crate-sized systems are designed, is 15 miles. The required number of vehicles in this system, determined using Equations (1)–(5), for pallet and crate systems with 20-s headways on the Houston–Satellite Port route is 122. The operating parameters of the three systems for the Houston–Satellite distribution center route (one system for each load type) can be summarized as shown in Table 8.

Table 8. Summary of operating parameters for each UFT size load in the designated Houston–Distribution Center Route [15].

Route	**Houston to Satellite Dist. Center**	**Houston to Satellite Dist. Center**	**Houston to Satellite Dist. Center**
Freight type	Shipping containers	Crates	Pallets
Length (miles)	14	14	14
Speed (mph)	45	45	45
Min. headway (sec)	30	20	20
Capacity (vehs/day/direction)	2880	4320	4320
No. of handlers (per terminal)	8	N/A	N/A
No. of forklifts (per terminal)	N/A	14	14
Vehicles circulating (at capacity conditions)	80	122	122
Fully loaded veh. weight (U.S. tons)	39	9.3	5.6
Loading/unloading platforms (per terminal)	6	12	12
Terminal area (acres)	21.5	21.3	8.7

16. Terminal Design

The objective of this section is to develop a schematic design for the UFT terminals for each of the three load types (shipping containers, crates, and pallets). The terminal design specifications include the rail facility design and layout, freight handling, highway access, planning and environmental considerations, and project time scales. The development of individual freight terminals demands a detailed approach for freight flows, handling processes, equipment selection, the role of information communication technologies (ICTs) in freight transport, and the operational and control rules. Therefore, the design and operating analysis of these systems were significant components in providing a state-of-the-art functional design.

16.1. Schematic Design of Terminal

A key component of the UFT terminal is the loading and unloading platforms. A total of six platforms (three loading and three unloading) were sufficient for the shipping container UFT system between Houston and Dallas. For the smaller-sized UFT systems (pallets and crates), due to shorter headways, 12 loading/unloading platforms would be necessary. If more loading/unloading areas were needed, the number of platforms could be increased to handle additional container flows.

Figure 7 shows a schematic layout of a typical UFT terminal for standard shipping containers as well as crates and pallets. As vehicles arrived, they were directed to the first available unloading platform. Bypass shunts were designed to alleviate queueing of arriving vehicles during the peak time. Unloading the freight on each platform by using a handler is estimated to take about 90 s. In turn, the minimum headway between consecutive vehicles could be as low as 30 s. Therefore, there is a potential for a traffic back-up without bypass shunts to allow vehicles to continue downstream of the track to the next available platform.

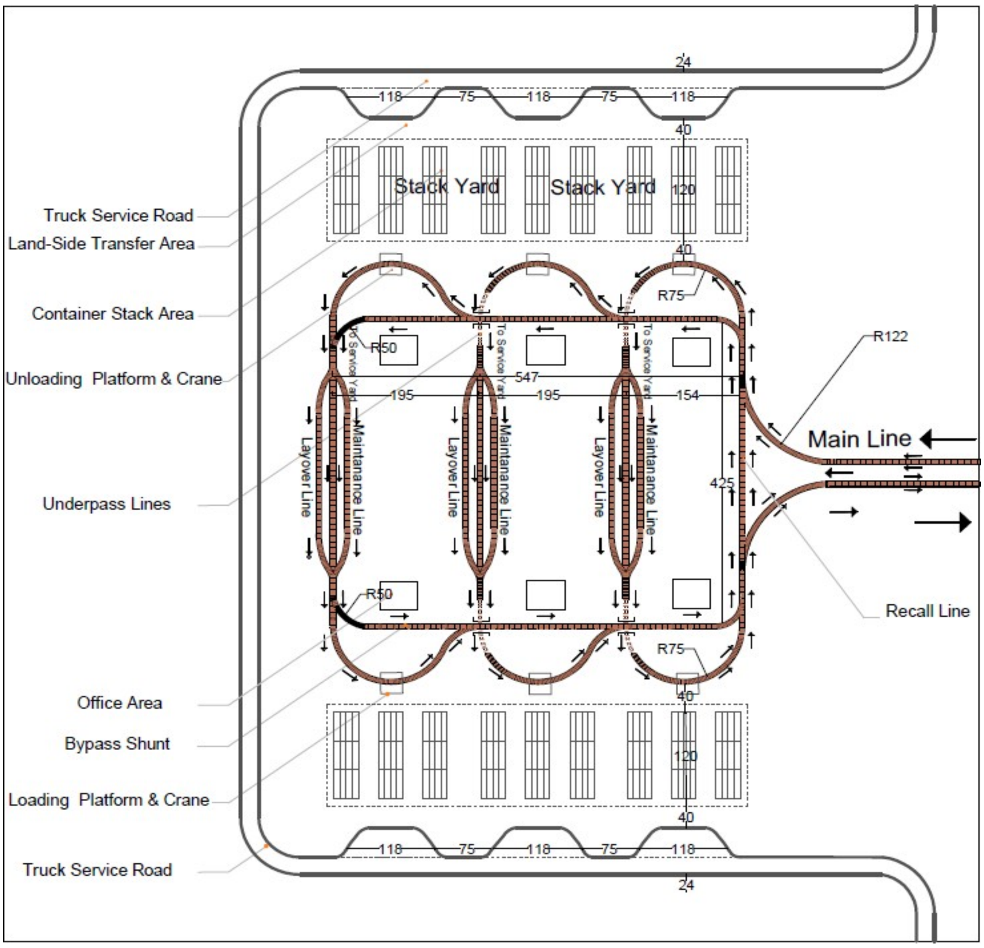


Figure 7. Typical terminal layout [15].

After unloading their freight, vehicles were directed beyond the loading platform through the underpass lines. Underpass lines pass beneath the bypass shunts and are designed with an approximate 10% grade. They direct the vehicles to the loading platforms or, if need be, to the layover and maintenance lines for service or repairs. Layover lines and maintenance lines run parallel to the main line to allow vehicles to return to the main line when needed. Vehicles then pass underneath a second bypass shunt and proceed to the outgoing loading platform to be loaded with outbound freight and be directed to the outgoing main lines.

16.2. Required Terminal Areas

The terminal area calculations entail the required areas for handler operations, stack yards, truck access, service yard, and vehicle storage and parking. Equation (7) yields the terminal area based on the pairs of loading/unloading platforms. For the shipping container terminals, it has a constant value (56,000 sq. yds.) for the first pair of loading/unloading platforms, and a variable section for each additional pair of loading/unloading platforms, as follows:

$$A = 56{,}000 + 24{,}000\,(N - 1) \tag{7}$$

where A = the total terminal area (sq. yds.), and N = the number of loading/unloading platforms.

The respective terminal area calculations for the two smaller UFT systems for crates and pallets are given in Equations (8) and (9), respectively.

$$\text{For crate UFTs: } A = 29{,}500 + 14{,}700\,(N - 1) \tag{8}$$

$$\text{For pallet UFTs: } A = 11{,}980 + 5990\,(N - 1) \tag{9}$$

Table 9 shows the required terminal area of each UFT system.

Table 9. Required terminal area for each UFT system [15].

Freight Type	Number of Loading/Unloading Platforms	Total Terminal Area (sq. yds.)	Paved Stack Yard Area (sq. yds.)
Standard shipping container	6	104,000 (21.5 acres)	32,900 (6.8 acres)
Crate	12	103,000 (21.3 acres)	16,200 (3.3 acres)
Pallet	12	42,000 (8.6 acres)	6850 (1.4 acres)

Each proposed route has two end terminals (no intermediate terminals). At each terminal, there were a number of loading/unloading platforms. Forklifts and handlers were required at each platform for loading and unloading the containers, pallets, or crates. For each platform, at least two forklifts/handlers were needed: one to load/unload vehicles and to haul the containers to the stacking yard and the other to load/unload the trucks. In each terminal, a total of four additional handlers/forklifts were recommended for backup. Table 10 shows the parameters related to handlers/forklifts in terminals for each of the three freight types (containers, crates, or pallets).

Table 10. Handler/forklift specifications and operational parameters [15].

Parameters	Container	Crate	Pallet
Load weight (U.S. tons)	34	3.5	2.3
Min load/unload time (min)	1.5	2	2
System capacity (vehs/day/direction)	2880	4320	4320
Number of platforms	6	12	12
Number of forklifts	N/A	12	12
Number of handlers	8	N/A	N/A

17. Benefit–Cost Analysis

Benefit–Cost Analysis (BCA) is a systematic method for comparing the benefits and costs of a project to determine its economic competence. The purpose of this section is to present the benefit–cost analysis of ULT for each design alternative. This analysis includes the calculation of three common economic feasibility measures to compare the benefits and costs of the proposed ULTs: Net Present Value (NPV), Benefit–Cost Ratio (BCR), and Internal Rate of Return (IRR). Table 11 summarizes the calculated economic measures for all five ULT alternatives. The values of the NPV and Benefit-Cost Ratio of each system along with the comparison of the system's Internal Rate of Return with the discount rates clearly show the economic viability of each proposed ULT alternative.

Table 11. Summary of calculated economic measures for various designed ULTs with discount rate of 1.5 [15].

Alternative	NPV	BC Ratio	IRR
Container-Sized UFT from Port of Houston to City of Lancaster (near Dallas)	USD 59.7 billion	3.77	12.44%
Container-Sized UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	USD 3.4 billion	3.3	11.6%
Crate-Sized UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	USD 1.1 billion	1.96	6.44%
Pallet-Sized UFT from Port of Houston to Inland Satellite Distribution Center in Baytown	USD 0.2 billion	1.24	3%
Container-Sized UFT for the Border between the U.S. and Mexico in Laredo, TX	USD 0.8 billion	2.48	9.92%

18. Results and Discussion

This research stands out for its innovative approach of merging technological research with the pursuit of fairness and economic chances for under-represented groups. A significant challenge for many young people is the distinct barriers to employment that limit their prospects in life. The project aims to delve into the creative and entrepreneurial spirit of the youth, as well as their employment requirements, deficiencies, and obstacles in meeting those needs. The Organization for Economic Co-operation and Development (OECD) defines 'disconnected youth' as individuals between the ages of 16–24 who are neither working nor engaged in education or training (NEET). In the U.S., it is estimated that there are 4.5 million (11.5%) NEET youths. Various local entities, including juvenile detention centers, school districts, municipal authorities, nonprofits, colleges, philanthropic groups, and private businesses, are actively seeking to develop training and job opportunities for these disconnected youths. Such a project would equip these stakeholders with data-driven insights into the life experiences of NEET youths and propose targeted strategies to improve their job prospects.

This research explored the schematic layouts for various freight containers, including standard shipping containers measuring 8.0 ft $\times$ 9.5 ft $\times$ 40 ft, crates with dimensions of 5 ft $\times$ 5.3 ft $\times$ 10.4 ft, and pallets sized 3.3 ft $\times$ 3.3 ft $\times$ 4 ft. The designs encompass several elements such as the conduit system, the capsules used as vehicles, the track-based conveyance system, access shafts, and the design of terminals and systems for transferring loads between modes of transport. Additionally, the paper addresses the operational aspects of ULT, formulating equations to calculate the necessary intervals between vehicles, the fleet size, and the number of handlers or forklifts needed for loading and unloading, all based on the demand for freight transport. The propulsion system, featuring LIMs and automated technologies, are highlighted as an efficient solution for moving freight of all sizes, including standard containers.

To enhance the understanding of the system's components and viable design options, the study reviews the literature on past tubular freight systems, whether they were theoretical proposals, pilot projects, or operational to a limited extent. The FHWA, with support from Volpe and the Volpe National Transportation Systems Center, among others, has conducted research in this area. The study pays special attention to significant advancements in transportation, such as Sydney's Freight Circle for moving containers from the Port of Sydney to multiple distribution centers, the container port development in Shanghai, and existing systems used in the mining sector. Additionally, the paper examines proposed systems like the New York Port Authority's ULT line by [41] and the Freight Shuttle System by [25]. These investigations, combined with feedback from those involved in the project, provide the foundation for the detailed designs of the ULT's various components. This encompasses the designs for vehicles and tunnels, tracks, propulsion and power systems, and terminals, as well as potential routes for both short and long hauls.

Additionally, the Social Science Research Council's 2017 report indicates that Texas is home to half a million young people, with a NEET rate of 13.8%, surpassing both the national average of 11.5% and Dallas County's even higher rate of 14.2%. The unemployment of NEET individuals leads to dire repercussions, including heightened poverty, criminal activities, and drug misuse. Specifically, black NEET youths endure a 26% rate of excessive institutionalization and criminalization, which is, in part, due to societal disruptions. Another less visible societal burden is the profound social and economic toll resulting from the disconnection of these youths from educational institutions and other societal structures. For example, Belfield calculated that the annual cost to the U.S. federal government for 6.7 million NEET youths is USD 32 billion, with state and local governments incurring an additional USD 61 billion in direct costs due to lost income, taxes, and expenses related to crime, health, and welfare. The introduction of a thoughtfully designed ULT could present a transformative future transportation framework, linking these isolated youths to the economic mainstream, thereby bolstering the economy, fortifying the middle class, diminishing inequality, and alleviating health disparities stemming from the absence of skilled labor.

19. Conclusions and Recommendations for Future Research

Success in ULT will enable logistics tubes to be built for transporting most of the cargoes currently transported by trucks, resulting in the following potential benefits:

- Reduced congestion and traffic jams on highways and streets, which will especially benefit cities that are heavily dependent on trucks for freight shipment;
- Reduced number of accidents caused by trucks, which improves highway safety;
- Reduced air pollution and greenhouse gases in cities where there is a large concentration of cars and trucks causing air pollution problems;
- Reduced consumption of diesel fuel and energy, since the energy required to transport each ton of freight over one mile of distance by freight tubes is only a fraction of that used by trucks;
- Reduced damage to highway infrastructures, including pavement, bridges, overpasses, etc., since trucks cause far more damage to pavements, although there are far more

cars than trucks on highways; therefore, the use of freight tubes will enhance the life of highway infrastructures and will reduce their maintenance cost [41];

- Improved transportation security, since underground freight tubes have controlled inlets and outlets and, hence, are more difficult for terrorists to sabotage than aboveground structures; also, unlike trucks, which could be used as truck bombs to attack other structures, freight tubes being fixed to the ground cannot be used as weapons aboveground.

Being able to use a part of the underground space of the existing highways, will greatly facilitate the construction of such pipelines and tunnels and reduce their construction costs. By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the leadership of the stakeholder committee, the objectives of this paper were to evaluate the use of ULT.

The research would focus on fostering multidisciplinary cooperation and establishing a Collaborative Stakeholder Engagement Group (CSEG). This group would consist of local stakeholders, residents, scholars, and civic groups from the Dallas–Fort Worth area. Graduate students and faculty from the University of Texas at Arlington (UTA) could offer training to under-represented youth on the workings of the ULT system. These young individuals would participate from the outset, engaging in discussions with researchers to understand the ULT's design and objectives. The researchers would formulate a comprehensive strategy tailored to the youths' needs. Subsequently, a separate project management team would organize the project's activities. In the third phase, NEET youth and community stakeholders would take part in the project's execution, ensuring it meets the requirements of all involved. This initiative represents the intersection of social and fundamental sciences, aiming to conduct effective research that addresses issues affecting human health disparities, social justice, and economic growth. Moreover, the project would span engineering, social sciences, and nonprofit sectors, enhancing the integration of disconnected youth into society and opening up new opportunities, thereby creating a socio-engineering model.

The required technologies exist and were proven, in practice, in other fields of transportation, but the combination on this scale is new and needs to be tested in the field. More challenging is the financial, social, and organizational engineering of the whole system. It is not a system that you can buy from the shelf. It is like reinventing the transport system all over again, with all the difficulties and hurdles to put it into practice. This means that research is needed. It is recommended that a project is implemented on an intra-city freight transportation route across a metropolitan area or on airport baggage transportation, such as using ULT to connect railroad or highway freight hubs or connecting part manufacturing to assembly plants. There is also a need to conduct computational fluid dynamics (CFD) simulations to enhance the analysis of the proposed methods and discuss how CFD simulations can optimize ULT design and operations.

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