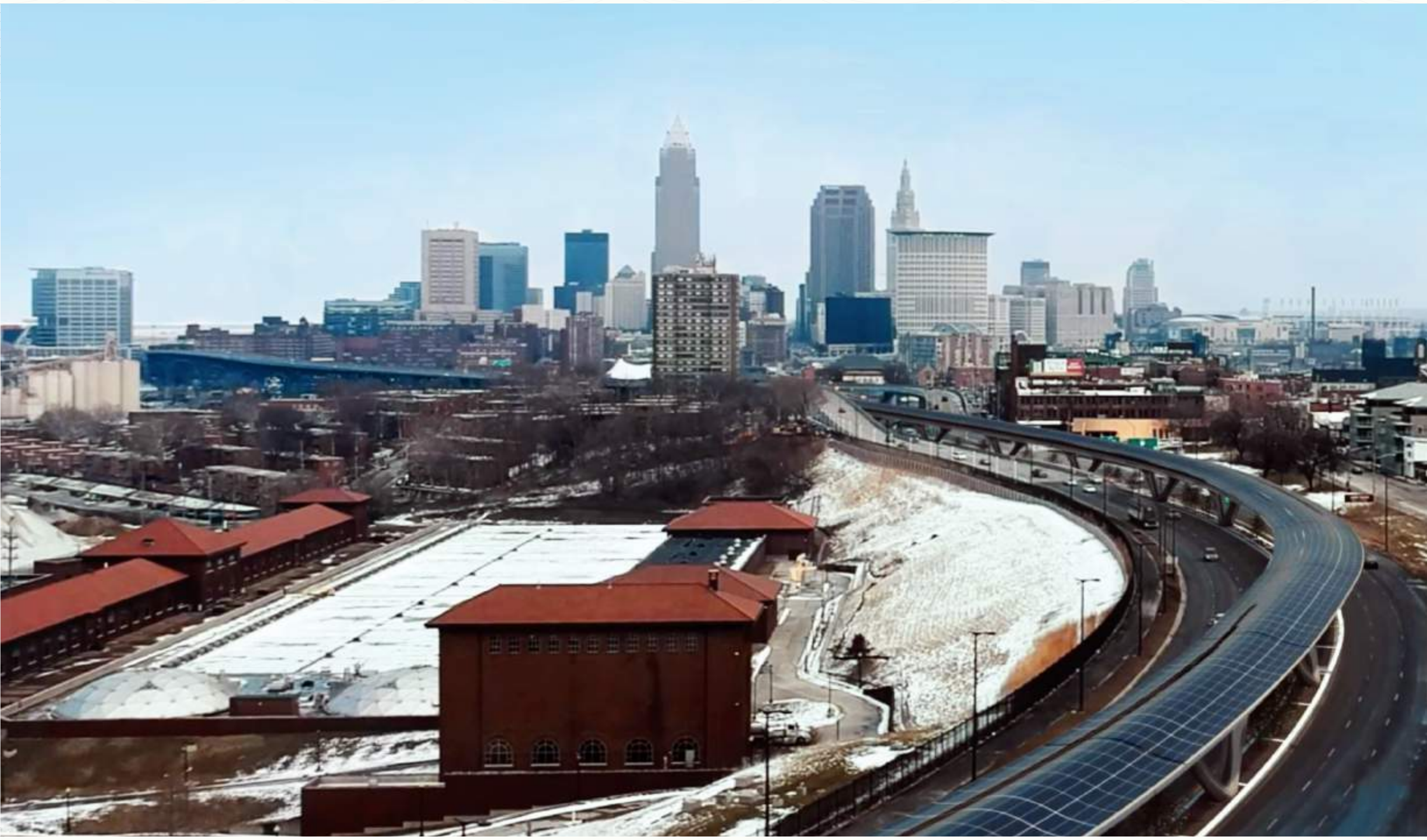
Great Lakes Hyperloop
Feasibility Study

Prepared by **Transportation Economics and Management Systems, Inc.**

Prepared for **Northeast Ohio Areawide Coordinating Agency**

In Cooperation with **Hyperloop Transportation Technologies, Inc.**



HYPERLOOPTT TEMS NORTHEAST OHIO AREAWIDE COORDINATING AGENCY

Final Draft | December 2019

Forward

On February 26, 2018, the Northeast Ohio Areawide Coordinating Agency (NOACA) and Hyperloop Transportation Technologies (HyperloopTT) entered into a public private partnership to complete a feasibility study for the technical analysis and evaluation of a Cleveland, Ohio to Chicago, Illinois corridor; known as the Great Lakes Hyperloop Feasibility Study.

The total cost of the study was $1.2M and each partner was responsible for 50% of the cost. The project launched on July 1, 2018. The NOACA portion of the project was funded through revenues from partners of NOACA: the Ohio Department of Transportation, the Ohio Turnpike and Infrastructure Commission, the Cleveland Foundation as well as NOACA. The project corridor was extended to Pittsburgh in June 2019 (increasing the cost by $100,000), with the RK Mellon Foundation being the newest funding partner. The project also has many collaborating partners such as: Illinois Department of Transportation, Indiana Toll Road, Federal Highway Administration, Eastgate Regional Council of Governments, Erie Regional Planning Commission, Southwestern Pennsylvania Commission, Team NEO, and Toledo Metropolitan Area Council of Governments.

The Northeast Ohio Areawide Coordinating Agency (NOACA) is the federally designated metropolitan planning organization (MPO) for Cuyahoga, Geauga, Lake, Lorain and Medina counties. NOACA performs planning for highways, bridges, public transit, bikeways and pedestrian facilities. The agency also conducts transportation-related air quality planning and functions as the areawide water quality planning agency.

NOACA’s 45-member Board of Directors, consisting of elected and appointed public officials from the five-county region, determines how federal transportation dollars are spent in Northeast Ohio. The agency works closely with local communities, county engineers, transit agencies, the Ohio Department of Transportation (ODOT), and other stakeholders on project planning, development and funding in a public forum. The agency takes a broad and balanced view of the region’s multimodal transportation system and seeks to preserve and improve the system throughout the entire metropolitan area.

Hyperloop Transportation Technologies Inc. (HyperloopTT) is a systems integration and mobility innovation company focused on realizing the Hyperloop. Through the use of unique, patented technology and an advanced business model of lean collaboration, open innovation and integrated partnership, HyperloopTT is creating and licensing mobility technologies.

Founded in 2013, HyperloopTT is a global team comprised of more than 800 engineers, creatives and technologists in 52 multidisciplinary teams, with 50+ corporate and university partners. Headquartered in Los Angeles, CA, HyperloopTT has offices in Dubai, UAE; Bratislava, Slovakia; Toulouse, France; and Barcelona, Spain. HyperloopTT has signed agreements in the United States, Germany, China, Ukraine, Slovakia, UAE, the Czech Republic, France, Indonesia, and South Korea.

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About the Hyperloop

The Hyperloop is an entirely new mode of transportation based on theoretical and experimental work in reduced pressure transport in the early 20th century. Hyperloop consists of a reduced pressure tube pathway, a passive magnetic levitation system, and a linear electric motor used to propel self-contained capsules carrying passengers and/or cargo. With a Hyperloop system, most of the air has been removed from the tubes, dramatically reducing aerodynamic drag, or air resistance. The passive magnetic levitation system levitates the capsule off the guideway, reducing or eliminating friction. This low air resistance and lack of friction makes it possible for vehicles to reach very high speeds. Since very little energy will be consumed due to air resistance, and magnetic drag actually reduces as speeds increase, much of the energy imparted to vehicles upon acceleration can be electrically recovered when the vehicles slow down. In addition, because of the lack of friction, vehicles will be able to accelerate on straight sections of guideway to very high speeds (700 mph+), exceeding even those of commercial jetliners.

As a fixed guideway system, the design concept for Hyperloop integrates some important elements from rail, but the system is equally akin to aviation and space systems since it shares many of the same characteristics as these modes. The Hyperloop will also be an extremely green and environmentally friendly technology. The system is completely sealed and electrically powered, which means that it will be very quiet in operations and emission free. In fact, by mounting solar panels on the tops of the guideway structure cladding, it has been estimated that the system could generate more electricity than it uses. The Hyperloop system will be both high-speed and resource-efficient, with a safe and comfortable experience for passengers and cargo. Depending on the regional topography and geologic features, the route corridor and guideway alignment can have subterranean or above ground applications. The Hyperloop can bridge over environmentally sensitive areas such as wetlands, or tunnel under dense urban landscapes.

Adoption of accessible ultra high-speed transportation has several spillover benefits separate and apart from the faster travel speed. Hyperloop mobility, as evaluated by the Great Lakes Hyperloop Feasibility Study, will directly affect: travel time, operating costs, safety, noise pollution, air pollution, carbon footprint, separation effect/property efficiency, interface with existing infrastructure systems (transportation, telecommunications, energy) and maintenance.

The Hyperloop will integrate engineering, operations and safety concepts from aviation and highway as well as from rail. This is why the Hyperloop has been called a “fifth mode” of transportation, since it doesn’t fit neatly into any of the existing established models, but rather it integrates design and operational concepts from a number of different existing transportation modes. Many of Hyperloop’s concepts are not really new, but rather integrate already proven technologies in a new way.

Why Cleveland to Chicago and Pittsburgh

Cleveland to Chicago represents a natural convergence of major interstate travel routes: I-80 from New York City, NY and I-90 from Boston, MA both come together at Cleveland and share the corridor to Chicago. I-76 feeds directly into I-80 from the east adding direct connections from Pittsburgh, Philadelphia, Baltimore and Washington, D.C. This geography naturally funnels traffic from the entire East Coast via Cleveland towards Chicago and beyond. As such, it is clear that a Cleveland to Chicago Hyperloop will develop into a critical component of a national Hyperloop network. Since a Cleveland to Chicago link is essential for making so many connections, this would be an excellent place to begin developing a national Hyperloop network.

Chapter 1

Project Overview

Summary

Chapter 1 of this report sets out the background and purpose of the Great Lakes Hyperloop Corridor Feasibility Study, including outlining the study's goal, the scope, and the methodologies used.

1.1 Introduction

The study provides a feasibility level of understanding about the basics of operating a Hyperloop service between Chicago, and Pittsburgh. Developing this service would enhance the US economy as well as that of all three cities. Using basic assumptions about route and technology options this report outlines estimates for the travel market, capital and operating costs, and potential financial and economic benefits of adding a Hyperloop service along the corridor. It will provide guidance on whether or not there is a case to be made for developing a Hyperloop corridor connecting Chicago and Pittsburgh via Cleveland, from a financial and economic perspective.

As background, since the early 1980's, there have been many changes in the travel environment including:

- The changing demographic and socioeconomic factors that have occurred in the intervening period reflecting greater mobility and a more widely distributed population.
- Changing travel conditions for auto use due to more congestion on the interstate highway system and higher energy (gas) prices that make auto travel more time consuming and expensive.
- Changes due to Air Deregulation that has significantly reduced the amount of air service for trips under 300 miles, and which has tended to concentrate more air travel at a few very large mega-hub airports.

- The development of Hyperloop as a real travel option for the corridor. This has been facilitated by the extensive investment that is being made not only by Hyperloop Transportation Technologies, Inc. (HyperloopTT) but also by several other companies who are bringing this new "fifth" mode of transportation to a state of commercial readiness.

As a result of these changes, auto and air travel have become less competitive, as travelers seek alternatives to these modes, even Amtrak has seen a significant rise in its ridership. For example, Chicago-Detroit Amtrak ridership increased by 57% between 2000 and 2011. This shows the readiness of the market to shift travel to a better alternative to flying or driving as soon as one becomes available. As a result, there is a convergence of the Hyperloop technology with the commercial readiness of the intercity travel market. Hyperloop is a new technology that is being developed just in time for meeting the emerging travel needs of the 21st Century.

As shown in Exhibit 1-1, the Cleveland-Chicago corridor represents a natural convergence of major interstate travel routes, since I-80 from New York and I-90 from Boston, both come together at Cleveland and share the corridor to Chicago. I-76 (the Pennsylvania Turnpike) feeds directly into I-80 (the Ohio Turnpike) from the east adding direct connections from Pittsburgh, Philadelphia, Baltimore and Washington D.C. This geography naturally funnels traffic from the entire East Coast via Cleveland towards Chicago and beyond. As such, it is clear that a Cleveland to Chicago Hyperloop will develop into a critical component of a national Hyperloop network. Since a Cleveland to Chicago link is essential for making so many connections, this would be an excellent place to start developing a national Hyperloop network.

Exhibit 1-1: Cleveland-Chicago is a Critical Link in the National Network

Exhibit 1-2 expands upon this concept by showing NOACA's vision for how the Great Lakes Hyperloop could eventually develop into a much larger network, that in the first two phases grows to blanket the Midwestern US, and then in a third phase extends east to link with the major east coast cities, and Canada. Regardless of the order in which the phases are actually developed, this shows how a Hyperloop network can evolve to provide national connectivity. As the network continues to expand, it will carry a significant volume of intercity passengers and freight.

The initial scope of this study only extended from Cleveland to Chicago, but it was agreed early-on by the Study Team that it would be beneficial to include an extension to Youngstown, OH as the first step towards a further extension (across state lines) to Pittsburgh, PA. NOACA later approved an extension to Pittsburgh, PA so the route could benefit from directly serving all three major cities, as well as number of smaller communities along the way.

This Phase 1 corridor will serve as a first step in developing a Hyperloop network. NOACA envisages further phases of development with the East Coast and the Midwest as shown in Exhibit 1-2.

Exhibit 1-2: NOACA Vision for Incremental Expansion of the Network

Hyperloop vehicles, guideways and operations are described in detail elsewhere, but several key characteristics of the technology are the most important in the development of routes and the selection of stations. These are:

- Hyperloop is a high-speed technology

  The capital and operating costs associated with a Hyperloop are found to be lower than those of traditional high-speed rail systems and as a result, perform well from a financial perspective and yield excellent Benefit-Cost returns. Because of its high-speeds, proposed Hyperloop alignments must be straight and curvature gentle, to achieve the intended performance of the system.

- Hyperloop uses individually propelled capsules rather than trains

  The use of individual capsules allows provision of direct point-to-point service between stations, without any stops in-between. As a result, capsules traveling directly between major cities will make no intermediate stops. For travel between smaller intermediate locations, direct capsules will be provided if traffic volumes are sufficient. If however two outlying locations (for example, Youngstown to Toledo) don’t generate enough riders to fill a capsule direct to destination, then passengers may need to travel via Hyperloop to a major transfer hub such as Cleveland and switch to another capsule that will take them to their destination. Even with such a transfer the overall travel time would likely be less than by any alternative transportation.

- Express freight traffic will contribute a significant share of Hyperloop revenues

  Freight capability needs to be engineered into the system, not just treated as an afterthought. Some freight such as express parcels can be handled as an adjunct to checked baggage service and would move as the equivalent of air “belly freight” on passenger capsules. Other freight may move in dedicated capsules, just as some air cargo moves on dedicated cargo planes. Hyperloop freight services will need to be tightly integrated with both surface and air transportation systems for efficient connections to LTL trucking and air cargo services. For example, if terminal operations could be co-located with connecting services, freight could be directly transferred from trucks or airplanes into capsules with a minimum of rehandling. This is essential to ensure that the inherent advantages of Hyperloop on the line-haul are not dissipated by inefficient terminals or high-cost truck drayage.

This study will provide the Northeast Ohio Area Coordinating Agency (NOACA), Hyperloop Transportation Technologies, Inc. (HyperloopTT) and other project stakeholders with a basic understanding of:

- The background and history supporting development of the Great Lakes Hyperloop Corridor.
- Potential route and construction alternatives for the corridor
- The market for intercity travel in the current and projected future travel environment
- The capital and operating costs of Great Lakes Hyperloop service
- The financial and economic benefits that would be derived from implementing the system

This study will assess the feasibility of developing a Hyperloop corridor with regard to the need for Hyperloop development in the corridor; capital costs; operation and maintenance costs; ridership and revenue; operating ratios and benefit-cost analysis; and the economic benefits to the community. It will not recommend a "preferred alternative" nor will it exclude any options from future consideration. The assessment assumes an approximate +/- 30% level of accuracy, with equal probability of the actual cost moving up or down. Additional work will be needed to develop more precise estimates. This will be done in the next stage of the planning process.

1.2 Project Scope

The study approach uses TEMS RightTrack™ Business Planning System to provide a fully documented analysis of the opportunity associated with the development of the Great Lakes Hyperloop corridor. The approach identifies the Business Case for developing the corridor in financial and economic terms, including an assessment of stakeholder and community benefits. Key deliverables include:

- A comprehensive intercity travel market analysis for the base and forecast years
- An assessment of potential routes and stations based on existing and historic analysis of options
- A review of potential operating schedules and travel times
- Both a financial and economic analysis of potential options and their ability to meet United States Department of Transportation (USDOT) funding requirements
- An assessment of community benefits for providing input to stakeholder and community groups to identify the project pros and cons
- Stakeholder and Public Outreach program and process
- Preparation of a feasibility report for use in assessing the project viability and its ability to attract suitable funding.

1.3 Project Methodology

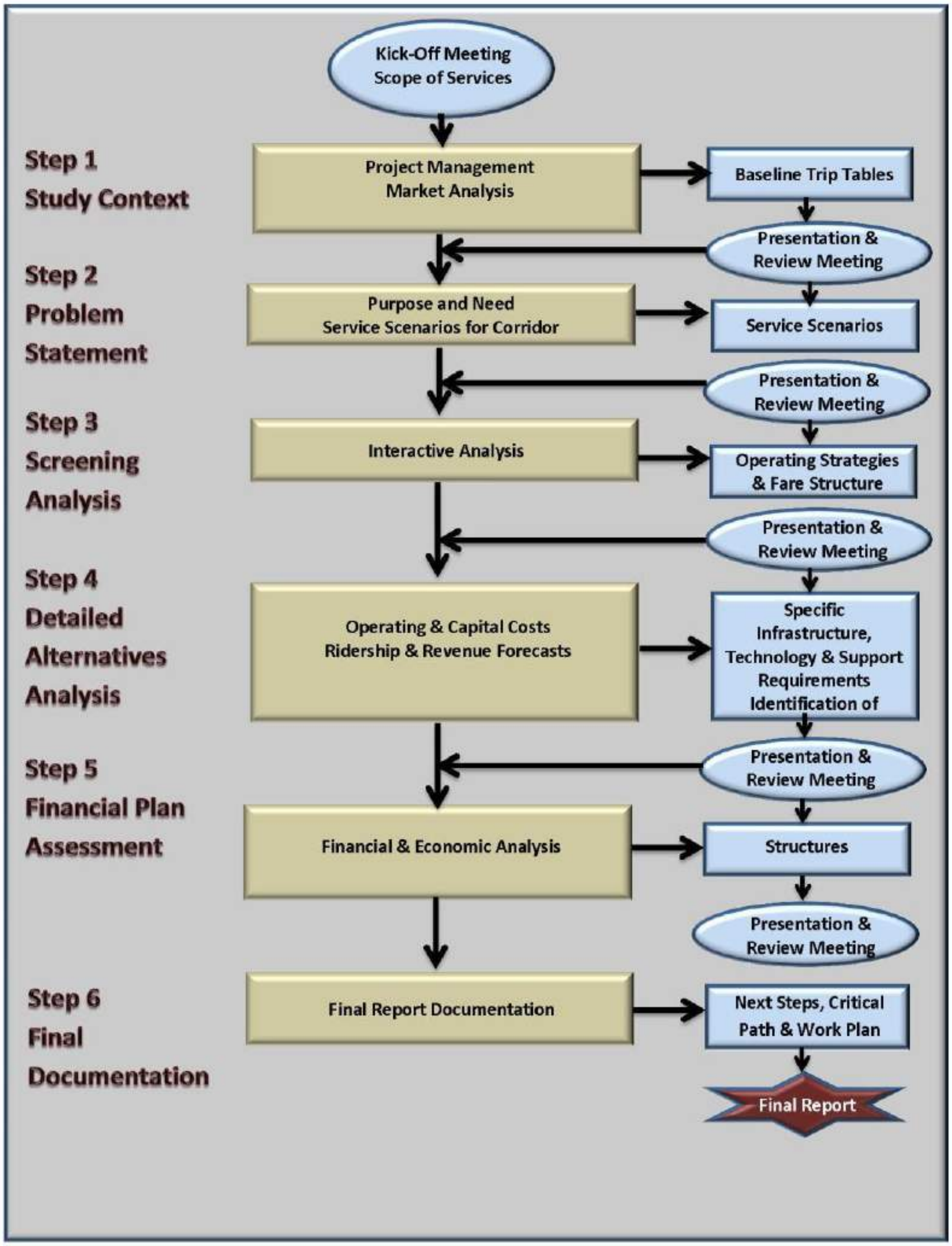
The Great Lakes Hyperloop Feasibility Study evaluates the feasibility of an interstate hyperloop network using the existing cost-benefit analyses for the Federal Rail Administration. The Project Partners utilized the HyperloopTT System embodiments for evaluative purposes; however, the study does not evaluate the economic feasibility for designing and constructing other embodiments of hyperloop technology from other hyperloop industry participants. In performing its economic evaluation of the hyperloop corridor, TEMS, Inc. relied on publicly available scientific, economic, and technical reports where available. Where the HyperloopTT System substantially differed from publicly available technical embodiments of other hyperloop systems, HyperloopTT contributed technical specifications and expertise for the benefit of performing the economic analysis, including where the HyperloopTT embodiments enable TEMS to perform their analysis relied upon the technical specifications.

To ensure that all of the USDOT FRA criteria and factors are fully evaluated, the study team followed the framework set by USDOT in its grant application guidelines. The economic evaluation framework specified by USDOT for all high-speed ground transportation modes (1997 Commercial Feasibility Study and BUILD Grant Program 2018) was used. As specified by the USDOT, the selection of an appropriate route option is "market driven." The difference in the selection of one option over another is heavily dependent on the potential ridership and revenue. A reasonable alternative has been developed for evaluation based on its potential to improve market access, raise speed, and reduce cost.

To ensure that market potential is properly measured, the TEMS Business Plan Approach carries out a comprehensive market analysis. The output of this market analysis is then used to determine the right alignment options and approach to developing the engineering infrastructure for the corridors.

In developing the Business Case, the TEMS team used the TEMS RightTrack™ Business Planning Process that was explicitly designed for high-speed ground transportation planning and uses the six step Business Planning Process as shown in Exhibit 1-3. Key steps in the process are the definition of the proposed service in terms of its ability to serve the market; an interactive analysis to identify the best level of service to meet demand, and provide value for money in terms of infrastructure; ridership and revenue estimates for the specific Hyperloop service proposed; and the financial and economic assessment of each option. The process shown in Exhibit 1-3 works the same for public, private or public/private partnerships approaches to developing the corridor since it develops all the information needed to support any kind of desired financial or economic assessment of the corridor.

Exhibit 1-3: RightTrackTM Six Step Business Planning Process

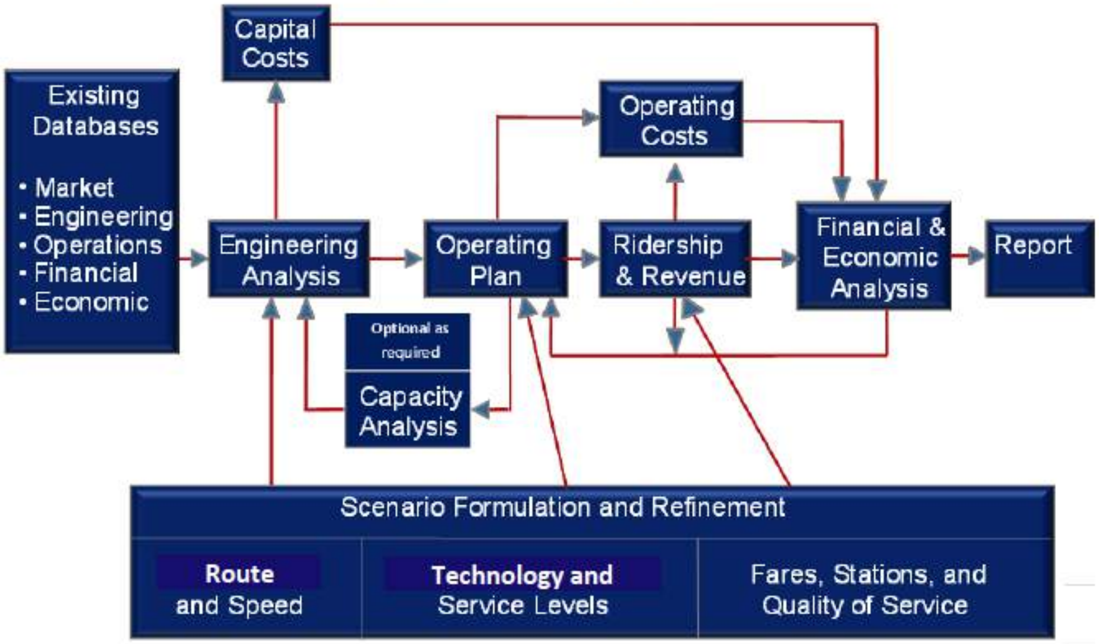


1.3.1 Study Process

The RightTrack™ Business Planning Process is designed to provide a rapid evaluation of routes, new or existing vehicle technologies, infrastructure improvements, different operating patterns and plans to show what impact these will have on ridership and revenues, and financial and economic results. Exhibit 1-4 illustrates the Interactive Analysis process that led to the financial and economic analysis.

The engineering assessment included GOOGLE© maps and/or ground inspections of significant portions of potential alignments, station evaluations, and identification of potential locations and required maintenance facility equipment for each option. TRACKMAN™ was used to catalog the proposed guideway infrastructure for several alternatives. LOCOMOTION™ was used to simulate the operation of capsules along the guideway based on the assumed operating characteristics (acceleration, curving capabilities, etc.) of capsules that were more limited by passenger comfort criteria than by the capabilities of the Hyperloop technology itself. The study identified infrastructure costs (on an itemized segment basis) necessary to achieve high levels of performance for the technology options evaluated.

Exhibit 1-4: Interactive Analysis Process



A comprehensive travel demand model was developed using the latest socioeconomic data, traffic volumes (air, bus, auto, and rail) and updated network data (e.g., gas prices) to test likely ridership response to service improvements over time. The ridership and revenue demand estimates, developed using the COMPASS™ demand modeling system, are sensitive to trip purpose, service frequencies, travel times, fares, fuel prices, congestion and other trip attributes.

A detailed operating plan was developed and refined, applying Hyperloop technologies and infrastructure improvements to evaluate travel times for each developed route alternative. Capsule frequencies were estimated to support and complement the ridership demand forecasts, match supply and demand, and to estimate operating costs.

Financial and economic results were analyzed for each option using the RENTS™ financial and economic analysis system. The analysis considers cash flows over a 30-year horizon using criteria recommended by USDOT Cost Benefit guidelines, and the U.S. Office of Management and Budget (OMB) Social Discount Rates. The analysis provided a summary of capital costs, revenues, and operating costs for the life of the project, and developed the operating ratio and cost benefit ratio for each option. In addition, estimates of the likely financial returns to private sector investors were also developed.

1.4 Organization of the Report

Chapter 1 Project Overview

Chapter 1 presents the overall approach for implementing the proposed Great Lakes Hyperloop corridor. Chapter 1 outlines the goals for the project, the project scope, and the methodologies used.

Chapter 2 HyperloopTT Technology and Approach to Corridor Development

This section discusses the development of Hyperloop technology, and provides background on the history and previous studies that have helped focus the current analysis and have led to identification of potential route options that were considered for this Study. This Chapter also provides an overview of the current regulatory issues associated with developing the project and licensing Hyperloop technology for use.

Chapter 3 Service and Operating Plan

This chapter discusses the development of the Service and Operating Plan, further detailing the development of route options that should be considered for the Great Lakes Hyperloop.

Chapter 4 Corridor Demographics, Socioeconomic and Transportation Systems

This chapter describes the zone system, socioeconomic data, transportation networks, origin-destination data, and values of time upon which the ridership forecast will be based.

Chapter 5 Hyperloop Ridership and Revenue:

This chapter develops the market analysis of the potential for Hyperloop passenger demand, presenting a Travel Demand Forecast for the corridor including ridership, revenue and market share results.

Chapter 6 Hyperloop Freight Market

This chapter focuses on the development of the express freight volume and revenue estimates that were used in the Great Lakes Hyperloop study.

Chapter 7 Capital Costs

This chapter includes a discussion of the capital cost methodology and a likely range of capital costs for developing the proposed Great Lakes Hyperloop.

Chapter 8 Operating Costs

Operating costs were calculated for each year the system is planned to be operational using operating cost drivers such as passenger volumes, capsule miles, and operating hours. The aim is to develop an affordable set of options that provide a high level of service at a reasonable cost.

Chapter 9 Financial and Economic Analysis

This chapter presents a detailed financial and economic analysis for the Great Lakes Hyperloop. This study sets forth the economic criteria for evaluation for both Public funding of a project as well as Public/Private Partnership criteria. It includes key economic measures such as the NPV Operating Surplus and Benefit/Cost Ratio at the Office of Management and Budget (OMB) prescribed discount rates.

Chapter 10 Public Outreach

This chapter describes the public outreach and stakeholder consultation efforts that were conducted in support of the Great Lakes Hyperloop study.

Chapter 11 Conclusions and Next Steps

This chapter outlines the key findings of the study, and the next steps that should be taken to move forward the development of the Great Lakes Hyperloop.

Chapter 2

HyperloopTT Technology and Approach to Corridor Development

Summary

This chapter discusses the development of the HyperloopTT technology. Next, the chapter presents an introduction to alignment design principles based on acceleration and deceleration of the Hyperloop capsule. Finally, this chapter provides a review of the background history and issues that have helped to focus the current analysis and that have led to identification of the route options that have been considered for the current study. This chapter also describes the current, relevant USDOT requirements (which may be subject to change through the NETT Council) as well as those of other state and federal agencies in order to obtain the environmental and regulatory clearances required for the project; as well as regulatory issues associated with developing the project and licensing Hyperloop technology for use. It should be noted that for the purpose of the study, it was agreed with Hyperloop Transportation Technologies, Inc. (HyperloopTT) to use its Generation 2 Technology, which is currently under development.

2.1 HyperloopTT Technology

Hyperloop is a tube-based inter and intra-city transportation system that travels at airplane speeds safely, efficiently, and sustainably. Passengers and cargo capsules, as shown in Exhibit 2-1, will levitate inside a tube using next-generation passive magnetic technology and a linear electric motor. By creating a low-pressure environment inside the tube using vacuum technology, aerodynamic drag is considerably reduced allowing for not only faster speeds, but a safer, cleaner and quieter form of energy-efficient transport.

Exhibit 2-1: Full-scale HyperloopTT Capsule, Courtesy of HyperloopTT

This concept of tube-based travel has been considered for over two centuries, but the technology has now matured so that each required HyperloopTT system and subsystem is available in some form in the marketplace. HyperloopTT conducts system engineering to integrate and optimize the existing technologies around the human passengers;

focusing first on safety, comfort, and the passenger experience as the primary design criteria while using efficiency, sustainability, cost reduction, and process optimization as objectives within the integration process.

HyperloopTT can be broken down into several core components as shown in Exhibit 2-2. The capsule is the vehicle that carries people and goods. The capsule begins and ends each trip on wheels and levitates using passive magnetic levitation technology above a targeted speed. Acceleration and deceleration is provided by a linear electric motor, with redundant emergency braking systems. The capsule and propulsion and levitation system are housed in a tube, which provides a boundary for maintaining a low-pressure operating environment. Vacuum pumps and valves maintain a safe and efficient environment inside the tube. Passengers and goods are able to enter and exit the system at stations and can exit the system along the route in emergency situations. An autonomous control system monitored by trained staff oversees all operations of the HyperloopTT system.

Exhibit 2-2: Full-scale HyperloopTT system, Courtesy of HyperloopTT

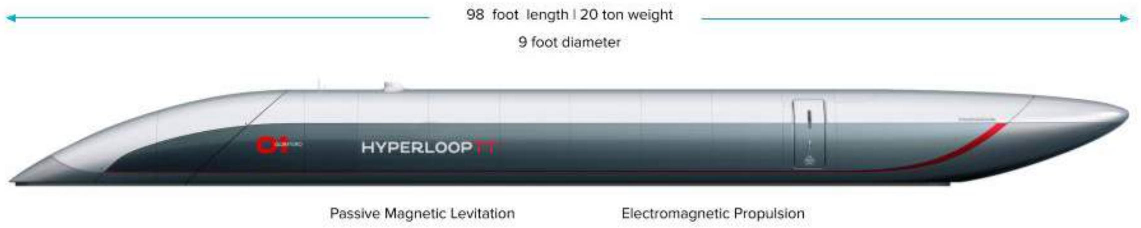
2.1.1 Tube, Capsule, and Vacuum System

The HyperloopTT System integrates accessibility within the overall system design process to anticipate the needs of passengers. The HyperloopTT station, capsules, and linear infrastructure are designed to be ADA compliant to accommodate passengers with luggage or other travel carry-ons. As the hyperloop market matures, station designers, capsule manufacturers, and connected transportation multimodal facilities will incorporate inclusive and accessible standards that meet and exceed the equivalent facilitation requirements for individual passenger dimension and anthropometrics.

Capsules include on-board systems and interior furnishings designed to maximize passenger safety, travel experience and comfort. On-board rechargeable batteries provide power supply to the capsule systems.

As shown in Exhibit 2-3, the fuselage is the outer shell and structural skeleton of the capsule and maintains the pressure boundary between the tube vacuum environment and the passenger cabin. The structural system is able to endure emergency tube re-pressurization at cruising speed. The fuselage is aerodynamically specified for the low tube pressure environment and design speed. The fuselage contains mounting equipment for all systems within the capsule and has at least two operational doors and two emergency doors. It has much in common with fuselage structures used and certified by the aerospace industry. HyperloopTT's suppliers can provide certified pressure vessels and plug-type door.

Exhibit 2-3: Capsule Prototype, Courtesy of HyperloopTT



Passenger safety and comfort will be ensured using an appropriate combination of best practices from rail and aerospace transportation. Robust capsule design uses proven aircraft technology and maintenance requirements to ensure that safety in the cabin area incorporates mature technology from certified partners.

Ride experience is tailored by minimizing the rate of change in acceleration (jerk) and avoiding coupling of axial and rotational movements. Rider experience and comfort is optimized through the use of augmented reality windows, lighting, colors, texture, and control of sound levels and frequencies. The cabin interior design is a world class comfortable environment worthy of this new mode of transportation.

Various capsule subsystems support the operations of the capsule. The capsule electrical system accepts power from the primary power system, stores energy for emergency backup, and transfers power to various auxiliary systems (e.g. lighting, entertainment system, etc.). These systems are similar to those which would be found on commercial aircraft or passenger rail vehicles. Heating, ventilation, and air conditioning systems maintain a comfortable environment for passengers and equipment. The primary thermal control system removes heat from various capsule components, and transfers heat to the heat storage module. HyperloopTT operating pressure presents a unique environment where dissipation of waste heat is difficult. A Heat Storage Module is proposed, in which waste heat is directed towards melting a frozen substance or toward a cooling tank. Relevant commercial applications include HVAC systems in buildings, ships, and spacecraft. Stored heat is transferred from the capsule during station operations, similar to battery recharging. As per industry standards all critical systems will have redundancies or backups. Capsules will have extra power and life support in the capsule in case the trip is prolonged, while multiple evacuation options for emergencies within the capsule, tube or operating system are considered.

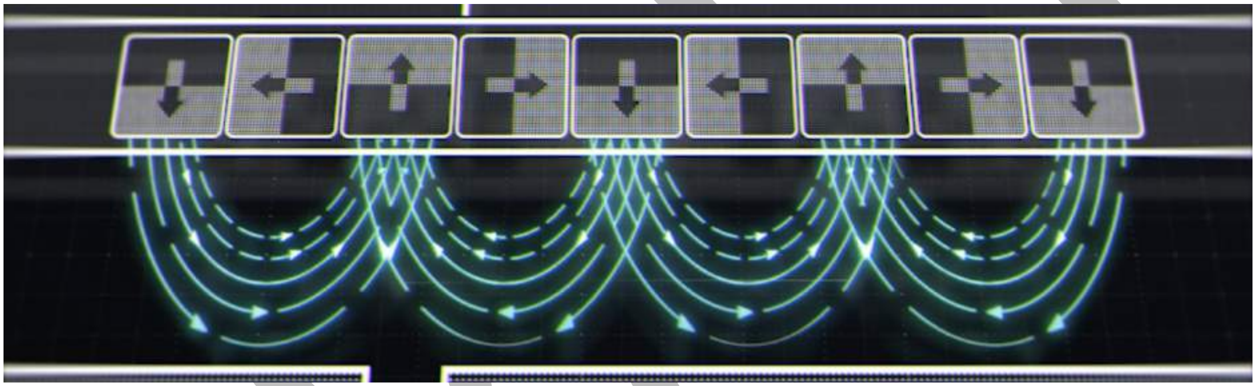
2.1.2 Levitation and Propulsion

The levitation and propulsion of the capsules will be provided by a passive magnetic levitation system in concert with linear motor propulsion. HyperloopTT has an exclusive license with Lawrence Livermore National Laboratories for use of its passive magnetic levitation technology. The movement of an array of permanent magnets, fixed to the capsule, over a conductive aluminium track causes a predictable passive levitation above a design speed. This system does not require power to generate levitation forces, unlike other technologies such as the Transrapid in Shanghai or to provide supercooling that enables levitation forces in Japan's Chuo Shinkansen.

A full-scale demonstration of this technology was performed by General Atomics at its facility outside San Diego, CA (FTA-CA-26-7025 (2005) General Atomics Low Speed Maglev Technology Development Program).

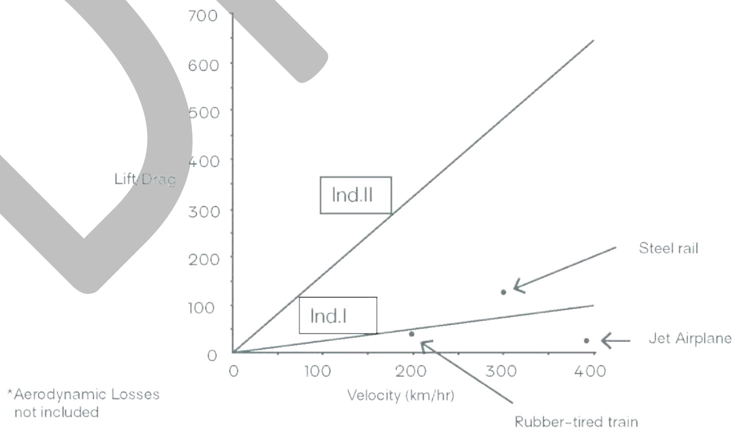
Exhibit 2-4: Full-scale Inductrack Demonstration, Courtesy of National Geographic

Exhibit 2-5: Inductrack illustration, Courtesy of HyperloopTT



As shown in Exhibit 2-6, Inductrack has a very high Lift to Drag ratio which continues to improve as the vehicle goes faster. Thus, once a capsule has been accelerated it will have neither aerodynamic nor any significant level of magnetic drag to slow it down.

Exhibit 2-6: Inductrack's Lift to Drag Ratios[1]



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[1] See: https://gcep.stanford.edu/pdfs/ChEHeXOTnf3dHH5qjYRXMA/09_Post_10_11_trans.pdf

The Inductrack system uses the passive magnetic levitation system for both vertical and horizontal guidance. When the capsule speeds are slow enough, levitation forces gradually decrease, and the capsule is lowered onto a low-speed track system that is present along the length of the guideway. The capsule then behaves similarly to a conventional fixed guideway wheeled-rail automated transit system.

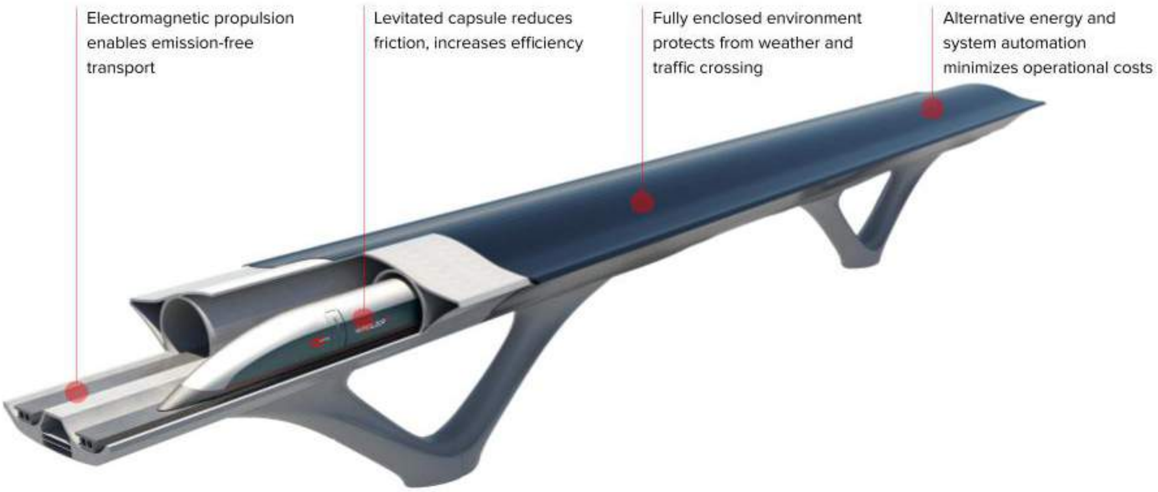
Linear motor technology provides propulsion force through an interaction between energized coils and permanent magnets or other conductive surfaces in a particular configuration. Power is provided to the energized coils through a system of transformers and inverters connected to the grid. Linear motors are in wide use in a variety of wheeled-rail and maglev systems, including several rapid transit and/or people-mover systems produced by Bombardier, Kawasaki, and others, as well as the Shanghai Transrapid.

Dynamic or regenerative braking makes use of linear motors in reverse to transform the kinetic energy of a moving HyperloopTT capsule to electric energy that recharges batteries, and in turn slows the capsule. Secondary braking systems including Eddy current and mechanical systems are also considered for redundancy.

2.1.3 Hyperloop Linear Infrastructure and Tunneling

The Linear Infrastructure develops the transportation corridor that passenger capsules travel through between station areas. The primary requirements are for a grade-separated tube shell that encloses a reduced-pressure environment and the levitation and propulsion guideway. The tube provides attachment points for communications, power, and safety systems. The tube may be elevated, with pylons supporting tube sections, or underground using cut-and-cover or deep tunnel configurations. Typical civil engineering principles are employed in the design of the structural capacity of the tube even considering the reduced pressure inside the tube.

Exhibit 2-7: HyperloopTT Elevated Infrastructure



The elevated guideway section will be used when the elevation difference between the planned profile and ground is less than 65 feet (19.8 m). A typical span is 100 feet (30.5 m). The tube structure is continuous over multiple spans, but it can be curved and the guideway internally super elevated to meet geometric and lateral acceleration requirements.

HyperloopTT is also collaborating with experts within the tunnel industry as well as emerging tunneling and rock breaking technology to accelerate the development of tunneling technology. In areas of variable terrain, or to pass underneath built-up urban areas, tunnels are appropriate to reduce unreasonable grades, maintain a smooth profile with long vertical and horizontal curves, and avoid surface disruption and visual impacts. Bored tunnels can be used for this purpose. These tunnels need to have at least 30 feet of overburden before a Tunnel Boring Machine (TBM) can be used. Depths shallower than this would be constructed by using open trenching and other transitional configuration methods. While highway and railway tunnels tend to be of very large diameter, HyperloopTT uses much smaller tunnels. At intervals of about 6 to 7 miles (9.7 to 11.3 km), an underground chamber and cross link between tubes will be constructed to enable emergency evacuation of capsules and access to the tubes for emergency and maintenance personnel.

For shallow tunnels, cut and cover techniques can be used. In urban areas, construction typically requires installation of underground retaining walls to reinforce both sides of a vertical excavation and prevent cave-ins. After this, the area between the walls is excavated and cross-braces are installed to reinforce the retaining walls. After the tunnel is complete the excavation can be backfilled, and the retaining walls removed. Utility relocation, if required, would be coordinated with the appropriate local utility. If extensive utility relocation is needed, a deep bored tunnel may be more economical. In a rural area it may be possible to excavate a trench and slope the ditch walls consistent with local building code requirements. When constructing alongside an active rail line or highway within 25 feet of the centerline of rail tracks or highway lanes, an underground retaining wall may be required to protect the rail or highway side of the excavation, determined in consultation with the rail or highway authorities.

Typical vacuum design principles and equipment are employed to maintain the pressure boundary. A bellows system is used to accommodate thermal expansion and contraction where needed and isolation valves are used to section off lengths of tube for repressurization. Several suppliers can produce suitable equipment.

Emergency escape ports are used to evacuate passengers from the capsule in case of emergency. In a preferred scenario, capsules are brought to refuge/escape zones which function as mini stations. These zones are expected to be located every 6 to 7 miles (9.7 to 11.3 km) and are expected to fit within 150% of the typical width of the Linear Infrastructure.

Secondary systems include vacuum pumps, vacuum control valves to isolate segments of tube and to provide safe repressurization, power stations, and emergency management equipment.

Air pressure inside the tube would be reduced to provide large reductions in aerodynamic drag. HyperloopTT's vacuum partner, Leybold, will provide a very reliable and nearly turn-key vacuum solution for the HyperloopTT System. This system will be optimized to achieve the target operating pressure in the tubes while minimizing energy consumption and maximizing operational uptime. Leybold has developed a "standard HyperloopTT vacuum unit" that fits within a standard shipping container. This container will contain all vacuum pumps and ancillary equipment (including electronics and cooling) and can be swapped in and out for off-site maintenance via relatively simple electrical and bellows connections.

Exhibit 2-8: Vacuum pumps and modular housing, Courtesy of HyperloopTT

It is anticipated that vacuum pump systems, power substations, communication hubs, and primary emergency refuge/zones will be co-located at approximately 6 to 7-mile (9.7 to 11.3 km) intervals along the length of the route.

The HyperloopTT system is designed to be net energy positive over the course of a year. This is achieved through efficient capsule movements where drag, even at high speeds, is drastically reduced through the use of passive magnetic levitation and through the use of the reduced pressure environment inside the tube. Additionally, the system is able to generate energy through solar panels and other renewable sources. Finally, the system is able to recover energy through regenerative braking as the capsules are slowed.

Solar farms would be developed at various locations along the corridor as needed, in partnership with local communities. This would extend the economic benefits of HyperloopTT into communities that may not currently possess the travel demand necessary for a station. For above-ground HyperloopTT tubes, solar panels are integrated within the tube cladding. For below-grade segments, easements may permit installation of above-ground solar panels. Utilities buildings, (e.g., locations that house vacuum pump containers, power electronics, and emergency escape refuges) are also suitable locations for roof-mounted solar and adjacently sited solar farms.

The HyperloopTT power system is designed to handle multiple challenges and to interact favorably with the existing electric grid. Primary equipment includes inverters and transformers, reactive power compensation devices, and cables to convey energy from renewable sources to the grid and provide needed power to the propulsion, vacuum and station systems. Active power management capabilities ensure a predictable, consistent flow of power to and from the existing electric grid.

Civil Works for HyperloopTT station locations will consist of site access and grading; site preparation for utility and foundations; stormwater management; installation of water supply and treatment, wastewater collection, treatment and disposal; and installation of building and pylon foundations, and on-site temporary and permanent roadways and parking facilities. These facilities will be designed to meet all local regulations and site conditions using typical engineering practices.

2.1.4 Hyperloop Stations

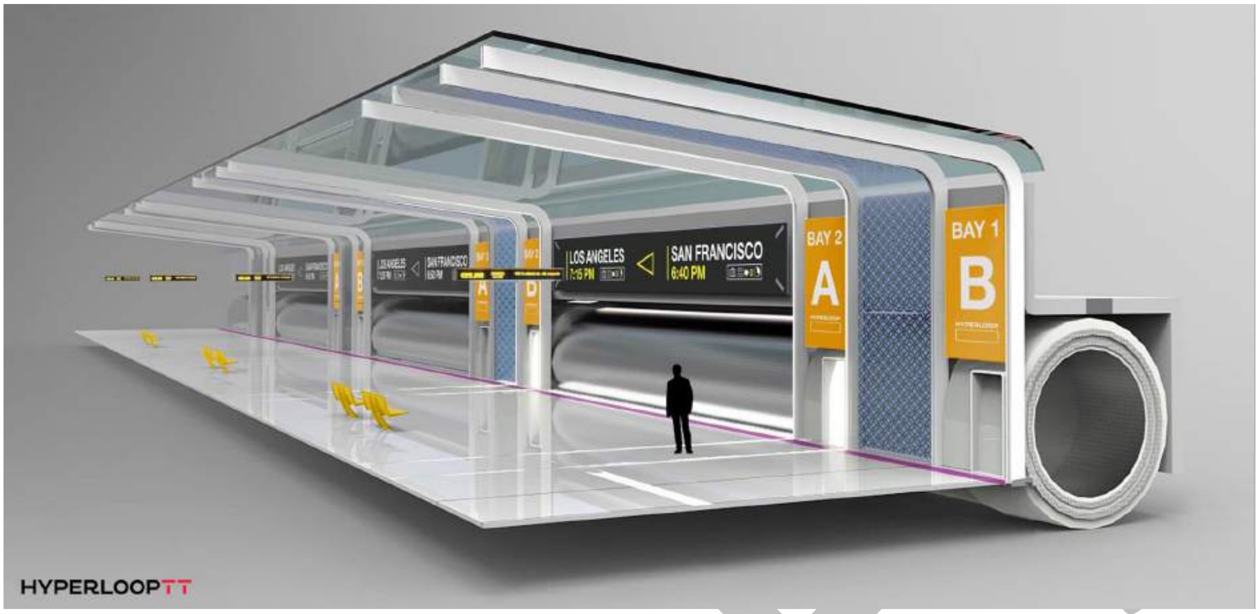
HyperloopTT stations will serve as the focal point of the HyperloopTT System where all transport functions and technologies converge. Station planning considers the complete passenger experience embracing access, ADA compliance, safety, security, movement, amenities and services, all in support of the passenger experience delivered in a sustainable, energy-efficient design.

Lessons learned from decades of experience in station planning for various transport modes recognize that passenger handling facilities must accommodate not only today's needs but also, to the extent practicable, tomorrow's passenger expectations. HyperloopTT combines the best attributes of passenger facility planning from airports, mass transit systems, high-speed rail and other transport technologies to a vision of future transport safety, efficiency, economy, and speed unrivalled by any transportation alternative.

The overall design concepts of the station guide passengers through the arrival and departure experiences. Physical wayfinding signage further guides and reassures passengers that they are on the correct path. Augmented reality is employed as state-of-the-art wayfinding for individualized passenger approach and navigation. Moving walkways and inclined ramps are important components, and themes of the HyperloopTT passenger experience. The experience of effortless, smooth movement with no waiting is realized and emphasized.

Exhibit 2-9: Station Concept Design, Courtesy of HyperloopTT

Exhibit 2-10: Station Concept Designs, Courtesy of HyperloopTT



Station gates enable the efficient transfer of people and goods from the station environment to the capsule environment before departure and after arrival. Fast battery and cooling recharge takes place during the alighting and boarding process.

The capsule navigates the station on powered wheels, with autonomous guidance similar to that found in autonomous guided vehicles in ports, warehouses, and other confined and controlled environments.

Several station configurations are under development as model solutions and comparative basis for design and analysis. The Dewdrop Station is inspired by creating a central geometry for passenger guidance. Passengers can walk along the curve as an efficient form of wayfinding. Capsules turning in the same operating direction as passengers is an elegant solution for high-demand capacity. One of the HyperloopTT system advantages is the ability to retrofit into existing systems and terminals. The HyperloopTT Plug-in Station is a strategy to add a new station to an existing HyperloopTT tube connecting city centers, or to retrofit a HyperloopTT portal into an existing train station, transit station, or airport.

2.1.5 Autonomous Operations

The HyperloopTT system is autonomous, with human supervision from Operations Control Centers. The system is designed for driverless operation of each HyperloopTT capsule. This autonomy is enabled by multiple interrelated functional systems. A control system manages, commands, regulates and acquires data from capsules, infrastructure and stations. A signalling system ensures safe capsule movements using principles from modern railroads and metro systems. A traffic management system plans, schedules and optimizes operations. A communications system exchanges data and coordinate control across the HyperloopTT system. The integrated system includes control and supervision of stations, maintenance operations, and response to alarms and emergency situations.

Relevant information will be communicated to passengers through indicator boards or digital communications to improve ridership convenience. The system status is monitored to ensure prompt recovery in case of irregularities. Functions are included to give warnings to maintenance staff based on health monitoring deployed throughout the system.

Travel by HyperloopTT will be as easy as arriving at a station and walking directly through to the gate, with minimal reliance on specific timing. Pre-booking and clearance of travellers will be common, and digital platform will combine HyperloopTT with existing modes of transportation to provide complete solutions including "last-mile" ground transportation.

To ensure system safety, up to 120 second headways are planned for the initial roll out of HyperloopTT operations, thus transporting up to 30 passenger capsules per hour in each direction, with a goal to shorten headway and increase capacity over time with operational experience and further assessment of in-service data. Station and tube infrastructure is designed to support headways as low as 40 seconds during peak periods. Operations will be dynamically scheduled based on historical data, advanced reservations, and intelligent monitoring of demand on wider transportation infrastructure.

2.1.6 HyperloopTT Research and Development Facilities

HyperloopTT engineering teams and industrial partners are analysing, simulating, designing, and prototyping to ensure technology readiness. A validation and verification process is shared with partners and suppliers in order to confirm the correct requirements were specified and that the technology works together as expected.

As of November 2019, HyperloopTT and its partners have constructed a full-scale test facility that will enable full-scale testing of all HyperloopTT system features except for speed. Key aspects of the linear infrastructure, propulsion, capsule, and autonomous control features are already being integrated and tested. The full-scale passenger capsule fuselage has been delivered and tested. Full-scale linear motor segments have undergone initial testing and further integration tests are underway. The steel tube is 13.1 ft (4 m) in diameter and 1,050 ft (320 m) long. The tube spans 131.2 ft (40 m) between supports, and is connected to a standard HyperloopTT vacuum unit. The vacuum unit and venting valves are able to be autonomously controlled from a remote-Operations Control Center.

Exhibit 2-11: HyperloopTT Toulouse Test & Certification Center, Courtesy of HyperloopTT

2.2 Environment and Regulation

To develop and prove this technology, HyperloopTT has developed a full-scale Research and Development test facility in Toulouse, France. The Toulouse test facility along with the Hyperloop Application - Generic Guideline for Design, Operation and Certification developed by TÜV SÜD will allow HyperloopTT to work closely with both European and United States authorities for developing a regulatory framework for the system.

2.2.1 Environmental Planning Process

This section will focus on the regulatory environment in the United States, particularly what measures need to be taken for getting the Hyperloop project built and the technology licensed for use in North America. In the absence of USDOT evaluation criteria specific to Hyperloop, the environmental planning process cannot be fully developed without further guidance from USDOT. In response to this need, on December 11, 2018 the USDOT established the Non-Traditional and Emerging Transportation Technologies (NETT) Council. The NETT Council will:

1. Identify and resolve jurisdictional and regulatory gaps associated with non-traditional and emerging transportation projects pending before USDOT, including with respect to:
    a. Safety oversight;
    b. Environmental review; and
    c. Funding issues.
2. Coordinate the Department's internal oversight of NETT projects and outside engagement with project stakeholders.
3. Develop and establish Department-wide processes, solutions, and best practices for identifying and managing NETT projects.

The NETT Council consists of the following members:

1. Secretary of Transportation, ex officio
2. Deputy Secretary of Transportation (Chair)
3. Under Secretary of Transportation for Policy (Vice Chair)
4. General Counsel
5. Chief Information Officer
6. Assistant Secretary for Research and Technology
7. Assistant Secretary for Budget and Programs
8. Administrators (or next most senior officer) from:
    a. Federal Aviation Administration

   b. Federal Highway Administration

   c. Federal Motor Carrier Safety Administration

   d. Federal Railroad Administration

   e. Federal Transit Administration

   f. Maritime Administration

   g. National Highway Traffic Safety Administration

   h. Pipeline and Hazardous Materials Safety Administration

9. Additional members may be added at the discretion of the Secretary or the Chair (e.g., Senior Advisor to the Secretary for Infrastructure)

10. Assistant Secretary for Government Affairs, ex officio

11. Director of the Office of Public Affairs, ex officio

The duties of the members of the NETT Council include:

1. Participate in all meetings and be prepared to share their experiences, challenges, and insights related to their work on NETT projects.

2. Recommend projects to the Chair for consideration by the NETT Council that warrant the establishment of a project-specific working group.

3. Work to resolve swiftly and amicably any intermodal disagreements over the Department's role in relation to NETT projects.

4. Identify statutory, regulatory, and policy issues that may represent impediments to timely project implementation and identify potential solutions or mitigation measures.

Discussions are currently ongoing with USDOT with regard to the environmental planning process for the Great Lakes Hyperloop project.

2.2.2 Licensing and Safety Regulation

The nature of Hyperloop technology itself eliminates many of the well-known hazards of existing transportation modes. For example, the system will be highly automated, which eliminates most of the human factor risks which prevail on existing transport modes. The system will be fully enclosed, which eliminates highway grade crossing, weather, and trespasser risks, which are the leading cause of deaths and injuries in the rail mode.

At the same time, there are still a number of safety unknowns that need regulatory review and approval. For example, the system must comply with fire codes designed to allow both for evacuation of passengers as well as safe emergency access by firefighters, police and other first responders. While HyperloopTT has concepts for how this can be done, these concepts will need to be detailed, vetted and approved by the responsible regulatory authorities. Another risk factor has to do with operation of the technology itself. Capsules are going to be operating at a very high-speed within a very low-pressure environment, so any collision or accident may have potentially serious consequences. HyperloopTT is going to have to explain and demonstrate how these events are going to be prevented, and if they do occur how the potential consequences can be mitigated. See also Chapter 8, Section 8.2.5 Insurance Costs.

2.3 Hyperloop Alignment Design Principles

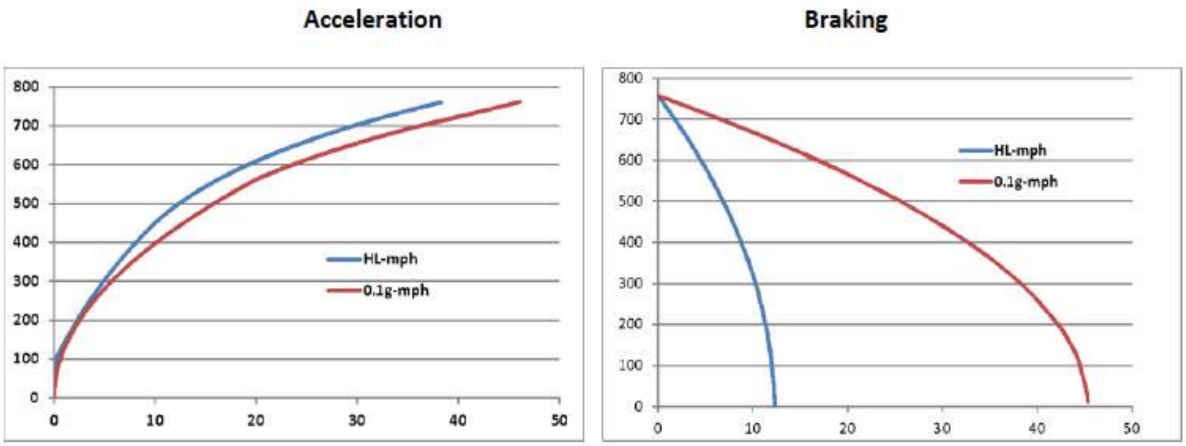
For this study, it has been agreed with Hyperloop Transportation Technologies, Inc. (HyperloopTT) to use accepted rail and maglev design practices for passenger comfort, and also because regulatory agencies like the USDOT Federal Railroad Administration (FRA) are well familiar with the existing standards. By using rail standards for laying out the alignment, passengers will not be subjected to severe or unaccustomed acceleration, braking or banking forces throughout the normal course of their HyperloopTT journey. In fact, it is likely that HyperloopTT riders would be subject to lesser dynamic forces than those experienced in an automobile. Acceleration limits as discussed in this chapter are used in the corridor development process to optimize speed, passenger comfort, and capital costs.

2.3.1 Longitudinal Acceleration and Braking

The USDOT Federal Railroad Administration (FRA) regards 0.1 g as a limiting acceleration for intercity passenger trains because it allows passengers to not wear a seat belt, to freely use the bathroom, and to handle food and drink without spills. Assuming this limit will not only ensure a comfortable ride for occupants but designing the electrical system only for 0.1 g would also reduce the capital cost of both the vehicles and guideway and allow for better energy recovery in regenerative braking compared to higher rates of acceleration. For the three representative routes that have been developed in the study, increasing the acceleration and braking rates would reduce Cleveland to Chicago travel times only by about 3-6 minutes.

This capability to stop faster than a vehicle can accelerate is a generic characteristic of any rail or maglev technology and is not specific to HyperloopTT's design. The normal braking method in the HyperloopTT system would be to operate the linear motor in "regenerative" mode and so the maximum braking rate would be given by the electrical capabilities of the motor. By maximizing the use of regenerative braking, a linear motor could recover nearly all the braking energy as electricity rather than wasting it as heat. Additionally, the HyperloopTT system will have a redundant emergency braking system based on eddy current braking. Exhibit 2-12 shows an example of possible acceleration and braking curves for a HyperloopTT capsule. The red lines show the acceleration and braking profiles that were used in the vehicle simulation. Using the FRA maximum of 0.1g in normal service, a distance of 45 miles is needed to accelerate to a full speed of 760-mph, and the same distance is needed for braking. The blue lines in Exhibit 2-12 are hypothetical and are intended to be illustrative of theoretical maximum performance. Since the blue line closely tracks the red line for acceleration, it shows that a linear motor would be designed only to support the planned 0.1 g acceleration and braking rate. However, for braking, the blue line shows that in an emergency, a vehicle could stop much faster than it can accelerate. If the eddy current brake exerts 0.275 g and the linear motor contributes 0.1 g of retarding force, then the vehicle would slow down at a rate of 0.375 g and could stop in about 12 miles from top speed.

Exhibit 2-12: HyperloopTT Capsule Acceleration and Braking Curves Comparison



2.3.2 Horizontal and Vertical Curves

Horizontal curves are necessary to develop feasible corridors considering various physical constraints including natural features, urban developments, and available right-of-way. Proper design of curves and speed profiles allows for optimization of corridors based on trip time, passenger comfort, and capital costs.

In the design of curves, spirals are needed to transition from the tangent to a circular curve. A spiral curve provides a gentle transition in lateral acceleration which greatly improves comfort. California High-Speed Rail has published a comprehensive Technical Memorandum[2] detailing many geometric requirements that are customarily applied in laying out High-Speed rail routes. By adding cant to offset centripetal force as in Exhibit 2-13, vehicles can go around curves faster. However, the FRA regulates the maximum "superelevation" values. For regulatory compliance and to avoid the requirement for passengers to wear seat belts, it has been agreed to assume a maximum 12^{o} cant in the guideway for this study, which is consistent with High-Speed Rail geometric standards. In practice, the maximum cant restriction provides either a limit on the radius of curves that can be navigated given an assumed operating speed or provides speed restriction given an assumed curve radius.

Additionally, a guideway cannot go from straight-and-level to a canted-and-curved without a transition. Cant is introduced by including a "spiral" curve to provide a smooth transition from zero radius and zero cant, to the desired constant radius and the cant of the curved section. The higher the speed and greater the curve, the longer the spiral needs to be. As shown in Exhibit 2-13, spirals have to be provided for both the entry and exit ends of a curve.

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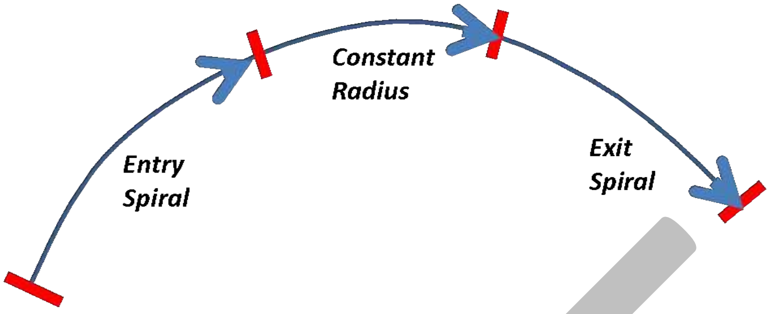
[2] *Alignment Design Standards for High-Speed Train Operation- TM 2.1.2*, prepared by PB for the California High-speed Rail Authority, March 26, 2009. Retrieved from http://www.hsr.ca.gov/docs/programs/eir_memos/Proj_Guidelines_TM2_1_2R00.pdf on May 6, 2019.

Exhibit 2-13: The Use of Spiral Transitions – Three Segments of a Horizontal Curve



As the spiral progressively tightens and cant increases, the vehicle rotates or "rolls." The length of spiral needed is directly proportional to the "rate of roll" of the vehicle. Faster rolls lead to shorter spirals, whereas higher speeds lead to longer spirals. However, if curves are spaced too closely together, especially in opposite directions, there may not be enough room between curves for inserting the needed spiral transition. In this case, the curves are said to "merge" and a shorter spiral than desired must be used. This has to be accompanied by a speed restriction to limit the roll rate of the vehicle.

Vertical curves, like horizontal curves, are necessary to develop feasible corridors considering various physical constraints including natural features, urban developments, and available right-of-way. Proper design of curves and speed profiles allows for optimization of corridors based on trip time, passenger comfort, and capital costs. The requirements for vertical curves, however, are more stringent than those for horizontal curves. The reason for this is that horizontal curves can to some degree be offset by superelevating or canting the track; but vertical curves have no possible offset. California's High- Speed ground transportation system standards[5] allow a vertical acceleration force no greater than 0.028 G.

Using these criteria suggests design choices to deliver a relatively flat alignment will enable highest speeds, while nominal speed restrictions would provide more flexibility in elevation changes.

Exhibits 2-14 and 2-15 summarizes the horizontal and vertical curve standards that have been used in this study as a function of speed, calculated using the standard engineering formula $\mathbf{r=v^2/a_c}$ and using g-force limits of 0.200 g for 12^o cant on horizontal curvature, and 0.028 g for vertical curvature following the California High-Speed ground transportation system standards, respectively.

Exhibit 2-14: Velocity vs. Horizontal Curve Radii (meters)

V (mph)	V (m/s)	12^o cant
56	25	319
112	50	1,276
168	75	2,870
224	100	5,102
280	125	7,972
336	150	11,480
391	175	15,625
447	200	20,408
503	225	25,829
559	250	31,888
615	275	38,584
671	300	45,918
727	325	53,890
760	340	58,893

Exhibit 2-15: Velocity vs. Vertical Curve Radii (meters)

V (mph)	V (m/s)	0.028g
56	25	2,232
112	50	8,929
168	75	20,089
224	100	35,714
280	125	55,804
336	150	80,357
391	175	109,375
447	200	142,857
503	225	180,804
559	250	223,214
615	275	270,089
671	300	321,429
727	325	377,232
760	340	412,251

2.4 Objectives for Route Development

For assessing the operational performance of the HyperloopTT technology, it was agreed early in the study process to limit acceleration, deceleration and lateral forces to those that passengers routinely experience in other modes of travel. Passenger high-speed ground transportation ride quality standards are conservative, but using them ensures that passengers do not need to use seat belts, and are able to freely get up and move around the vehicle and use the bathroom without restriction, as is the case with rail travel today. By developing straight alignments and using gentle curves, high- speeds can be achieved without needing to use any severe acceleration, braking or curving forces. This approach is intended to deliver both very fast travel and excellent ride quality and passenger comfort on board the HyperloopTT capsules.

Routes have been developed based on discussions with NOACA and HyperloopTT. Many of the alignment options have been further refined as a result of the Interactive Analysis process during the capital cost development phase. For developing routes as the basis for feasibility evaluation, it is essential to select routes that respond to the needs of the region, regional employment and growth projections, and that provide for the long term development of HyperloopTT network connectivity as it relates to the overall development objectives of the region. In recognition of the goal for enhancing network connectivity, the initial study corridor from Cleveland to Chicago has already been extended east to Pittsburgh with a view towards eventual further network expansion.

Exhibit 2-16 shows the proposed Chicago-Cleveland-Pittsburgh corridor along with six Super Zones (Chicago, South Bend, Toledo, Cleveland, Youngstown, and Pittsburgh) defining the potential market areas along the route. (A straight-line has been added showing direct connections between the cities.) Exhibit 2-17 shows the base year and forecast demographics. The focus of this study has been to develop the most effective connections possible between Cleveland and the other two large cities. However, both Toledo and South Bend lie directly along the straight line that connects Cleveland to Chicago, and Youngstown lies directly along the straight line that connects Cleveland to Pittsburgh. As a result, intermediate stations can be added at these points without disadvantaging the through capsules that will run directly between the major endpoint cities.

The exhibits in this section show the aggregate socio economic projection for the whole study area. It should be noted that in applying socioeconomic projections to the demand model, separate projections were made for each individual zone using the data from the listed sources. Therefore, the socioeconomic projections for different zones are likely to be different and thus may lead to different future growth in sub-market super zone projections.

Exhibit 2-16: Chicago-Cleveland-Pittsburgh Super Zones of Key Markets

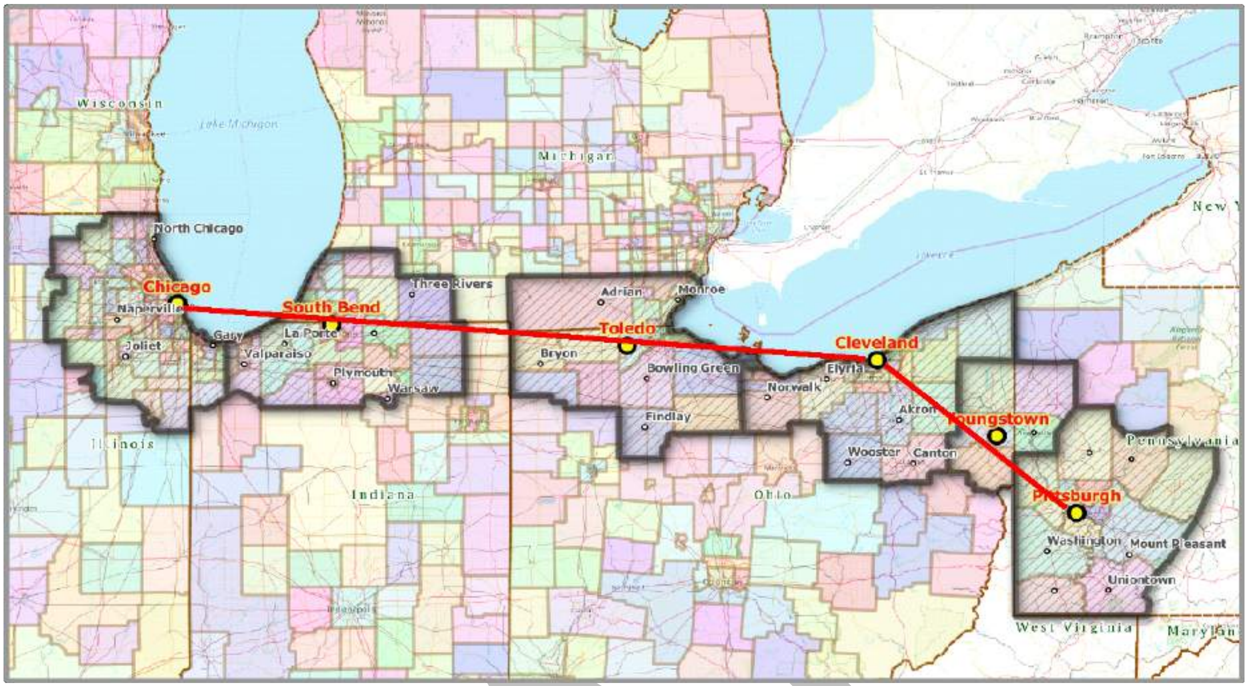


Exhibit 2-17 shows the population projections from 2020 to 2050 in the corridor by super zones. According to the data developed by TEMS, the population of the corridor will increase from 18.53 million in 2020 to 19.55 million in 2050. The annual population growth rate between 2020 and 2050 is 0.18% in the corridor.

Exhibit 2-17: Population Projection

Super Zone ID	Super Zone_Name	Super Zone State	Pop (2020)	Pop (2030)	Pop (2040)	Pop (2050)
1	Chicago	IL-IN	9,301,266	9,820,473	10,230,451	10,521,483
2	South Bend	IN-MI	1,290,356	1,353,305	1,400,188	1,429,671
3	Toledo	OH-MI	1,241,187	1,260,778	1,262,819	1,247,819
4	Cleveland	OH	3,491,093	3,494,427	3,450,766	3,363,592
5	Youngstown	OH-PA	737,815	722,874	697,442	662,946
6	Pittsburgh	PA	2,468,567	2,451,677	2,401,902	2,322,451
Grand Totals			***18,530,284***	***19,103,534***	***19,443,569***	***19,547,962***

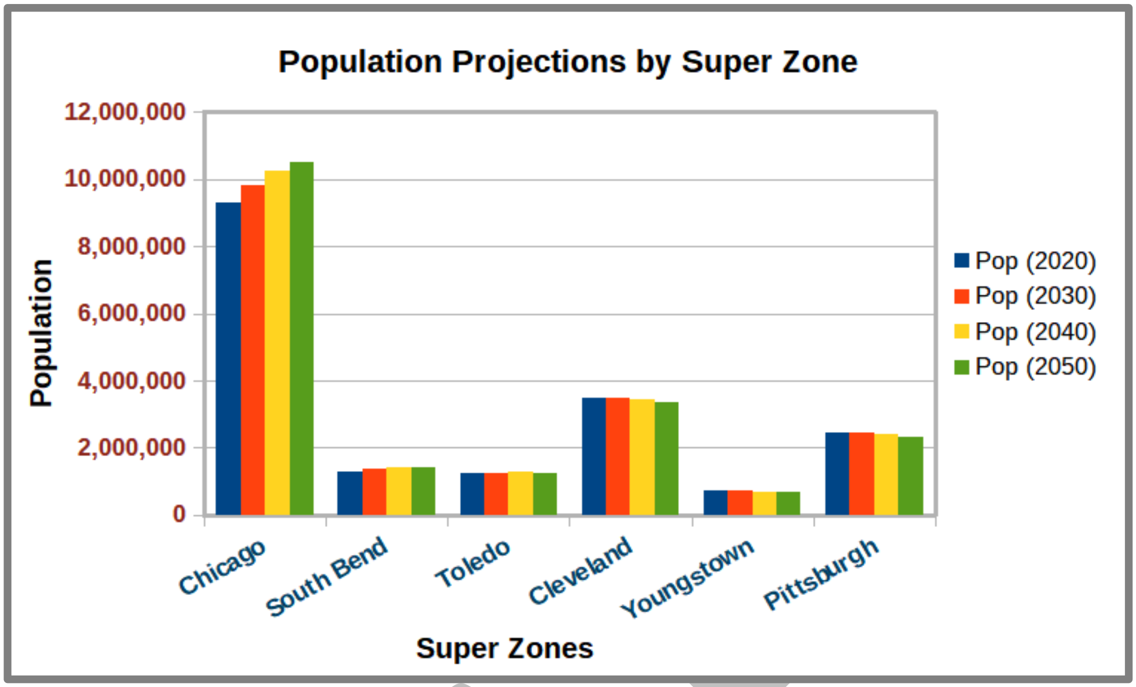


Exhibit 2-18 shows the employment projections from 2020 to 2050 in the corridor by super zones. It can be seen that the employment of the corridor will increase from 9.85 million in 2020 to 12.34 million in 2050. The average annual employment growth in the corridor between 2020 and 2050 is 0.76%.

Exhibit 2-18: Employment Projection

Super Zone ID	Super Zone_Name	Super Zone State	Employ (2020)	Employ (2030)	Employ (2040)	Employ (2050)
1	Chicago	IL-IN	5,038,704	5,619,316	6,151,761	6,651,939
2	South Bend	IN-MI	644,921	698,099	742,881	781,825
3	Toledo	OH-MI	636,721	672,222	697,919	717,695
4	Cleveland	OH	1,849,120	1,999,245	2,124,180	2,232,967
5	Youngstown	OH-PA	358,763	375,256	384,829	390,092
6	Pittsburgh	PA	1,318,421	1,416,695	1,496,428	1,564,746
Grand Totals			*9,846,650*	*10,780,833*	*11,597,998*	*12,339,264*

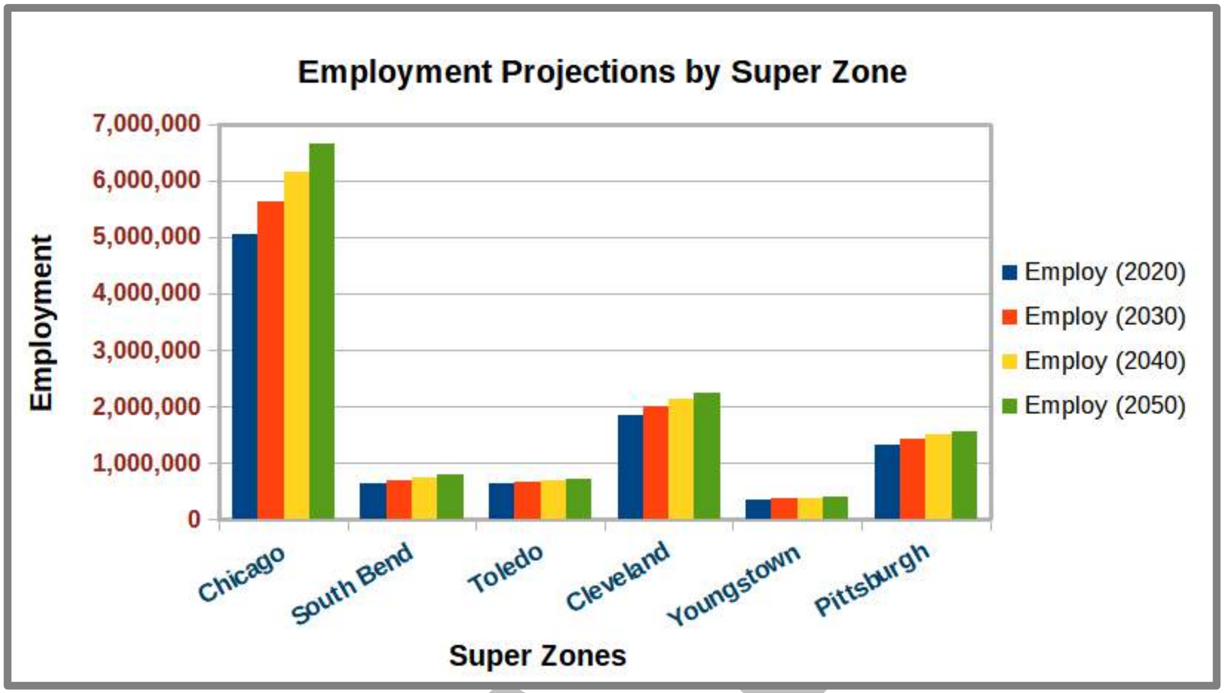
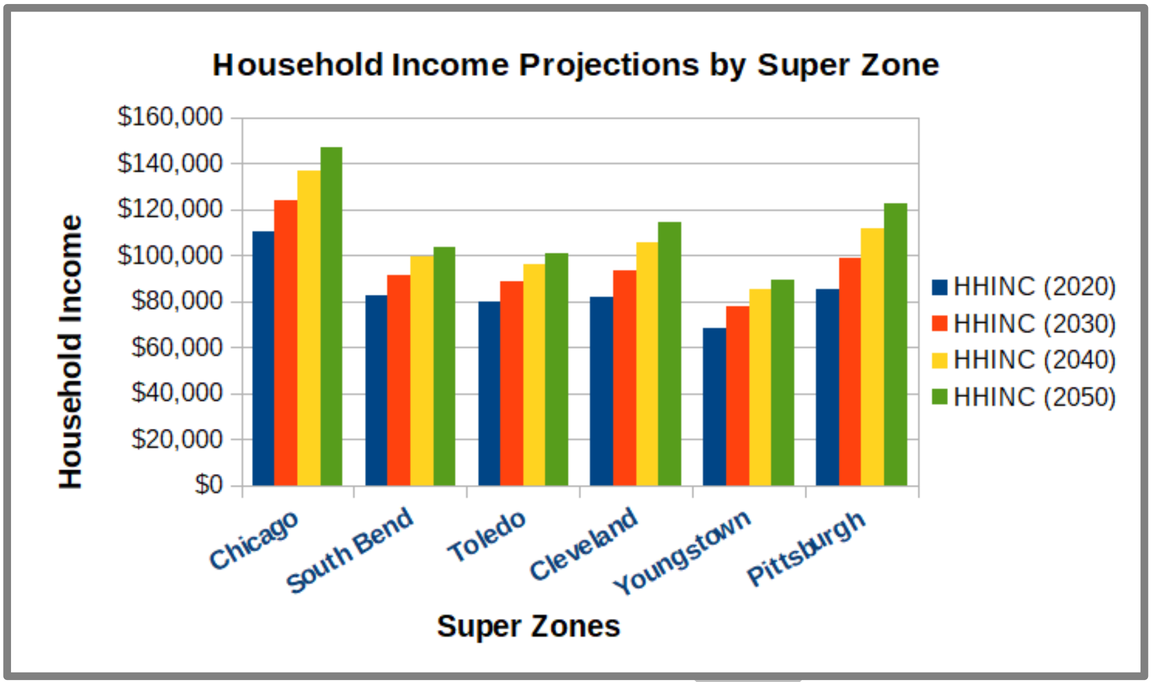


Exhibit 2-19 shows the household income projections from 2020 to 2050 in the corridor by super zones. It can be seen that the average household income in the Chicago area will increase from $110,175 in 2020 to $146,865 in 2050 at annual growth rate of 0.96%. Average household income in Cleveland area will increase from $81,594 to $114,624 from 2020 to 2050, the average annual growth is 1.14%. The average household incomes in other areas of the corridor have similar annual growth rates ranging from 0.9% to 1.2%.

Exhibit 2-19: Income Projection

Super Zone ID	Super Zone_Name	Super Zone State	HHINC (2020)	HHINC (2030)	HHINC (2040)	HHINC (2050)
1	Chicago	IL-IN	$110,175	$123,586	$136,878	$146,865
2	South Bend	IN-MI	$82,213	$91,448	$99,189	$103,699
3	Toledo	OH-MI	$79,992	$88,841	$96,298	$100,680
4	Cleveland	OH	$81,594	$93,558	$105,189	$114,624
5	Youngstown	OH-PA	$68,413	$77,504	$84,917	$89,562
6	Pittsburgh	PA	$85,163	$98,543	$111,499	$122,375



Based on the demographics shown above, it can be seen that the Youngstown and Pittsburgh zones together nearly match the population and employment of Cleveland; from this simple metric it can be seen that a Pittsburgh extension would likely double the ridership (100% or more increase) while resulting in only a 43% increase in the length of the corridor, since the distance from Cleveland to Pittsburgh is less than half the distance from Chicago to Cleveland. The only super zone exhibiting strong population growth is Chicago, although Cleveland and Pittsburgh are still adding a significant number of jobs. Incomes also are still growing, so this is leading to a rise in demand in part due to the effects of the income and employment variables on forecasted travel demand. However, rising traffic congestion on other modes as well as rising fuel prices, will create a diversion from auto and also contributing to the forecasted future increases in HyperloopTT potential demand.

Chapter 3

Service and Operating Plan

Summary

This chapter discusses the development of the Service and Operating Plan, including identifying the route options that should be considered for the Great Lakes Hyperloop. It identifies the kinds of engineering issues that would have to be addressed in the development of actual HyperloopTT alignments. This chapter also develops the point-to-point running times for each route option. The representative routes should not be understood as specific alignments because the alternatives have not been fully assessed or optimized in a detailed environmental study. The focus is to characterize an affordable set of preliminary options that could have the ability to provide a high level of service at a reasonable cost

3.1 Introduction

From Chicago to Pittsburgh, two different "representative" routes have been developed, along with a conceptual "Straight Line" route only from Chicago to Cleveland, as shown in Exhibit 3-1:

- Alternative 1 The Straight Line Route

  This conceptual route connects Cleveland Airport to Chicago on as close to a straight line as possible. Two sections of alignment tunnel underneath the Great Lakes, although by shifting the alignment slightly south, the length of underwater tunneling has been reduced. The original concept for the Straight Line, which connected downtown Cleveland to Chicago, passed through southern Michigan just north of the Indiana state line and bypassed both Toledo and South Bend. Since the alignment has now been shifted slightly south there is now an ability to incorporate some parts of the Straight Line alignment into the Toll Road Route between Toledo and South Bend. Further straightening of the Toll Road option could be considered as part of a future Tier I EIS.

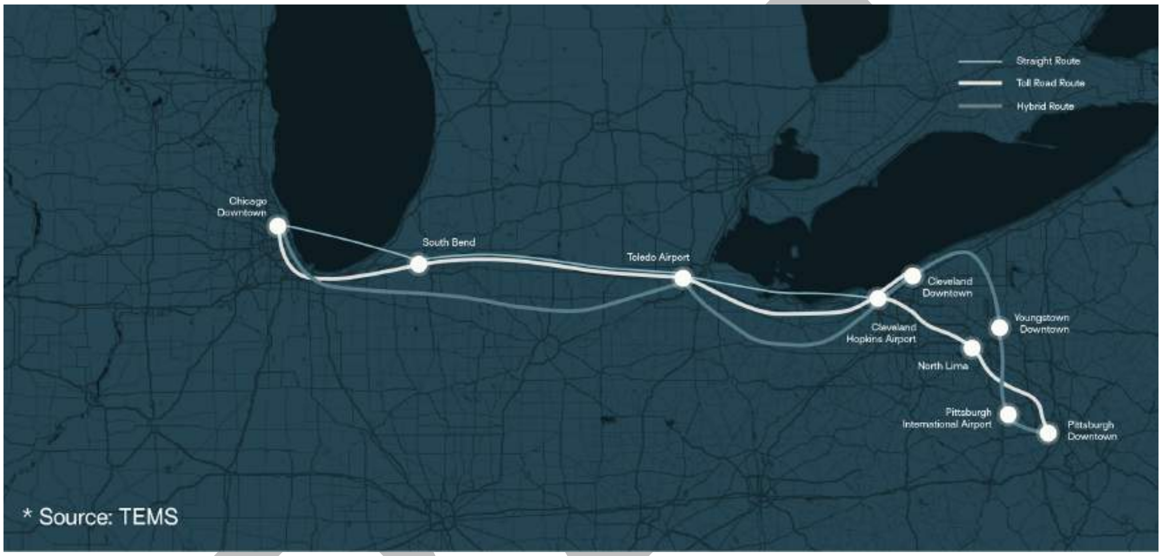
- Alternative 2 The Toll Road Route

  The original concept utilized the existing highway alignment, but this proved to be too curvy for Hyperloop. A new alignment was developed generally paralleling the Ohio and Indiana Turnpikes, but not confined to the geometry of the existing highway. The prospective Hyperloop alignment tends to go straight while the highway zig-zags and crosses it in numerous locations. This option has been extended to Pittsburgh along the Pennsylvania Turnpike.

- Alternative 3 The Hybrid Route

  This proposed Hybrid Route would utilize several sections of very straight existing rail and highway segments to minimize the need for property access, although some greenfield interconnections between usable segments of existing rail and highway alignment are still needed. As a result, the route is a hybrid that maximizes the use of existing straight rights of way. This option was extended along a new alignment via downtown Youngstown and Pittsburgh Airport to Pittsburgh.

Exhibit 3-1: Great Lakes Hyperloop Feasibility Study Corridors



* Source: TEMS

To develop an “apples to apples” comparison of the performance of the three Cleveland-Chicago options:

- The options were first assessed in terms of end-to-end Cleveland to Chicago ridership without any intermediate station stops.
- After this, intermediate stations were added to the Hybrid Route at Cleveland Hopkins Airport and Toledo, and then an extension to Pittsburgh with an intermediate station at Downtown Youngstown, Pittsburgh Airport and downtown Pittsburgh was also tested.
- Finally, intermediate stations were added to the Toll Road Route at Cleveland Hopkins Airport, Toledo and South Bend, and then an extension to Pittsburgh with an intermediate station at North Lima and downtown Pittsburgh was also tested.

Exhibit 3-2: Great Lakes Hyperloop Feasibility Study Stations

Stations	Straight	Toll Road	Hybrid
Chicago Downtown	✓	✓	✓
South Bend	✓	✓	
Toledo Airport	✓	✓	✓
Cleveland Hopkins Airport	✓	✓	✓
Cleveland Downtown		✓	✓
North Lima		✓	
Youngstown Downtown			✓
Pittsburgh Airport			✓
Pittsburgh Downtown		✓	✓

3.2 Description of Representative Routes

Three representative routes have been developed from Cleveland to Chicago: Straight line, Toll road and Hybrid routes. Specific alignments have been developed for the purpose of this assessment but at the current level of study are preliminary. When the project reaches the environmental planning stage the retained alignment options will be subject to further discussion with the tollway authorities, state DOTs and other potentially impacted entities, such as railroads and utility companies. The Toll road and Hybrid routes have each been extended farther east from Cleveland to Pittsburgh. As a result, one Cleveland to Chicago option and two Pittsburgh to Chicago options have been developed. In both Berea and North Lima, Ohio, the Toll road and Hybrid alignments cross one another and it could be possible to interconnect or mix-and-match the routes. However, for the purpose of this chapter the three options will be described as three independent alternatives.

3.2.1 Straight Line Route from Cleveland, OH to Chicago, IL

The straight line route has been developed largely as a conceptual alternative. It connects Cleveland to Chicago on as close to a straight line as possible. The original straight-line distance from downtown Cleveland to downtown Chicago was 310 miles. However, the alignment was shifted south, so it now follows a direct course from Cleveland to Chicago. This reduces the length of the underwater tunnel from 146 miles to 69 miles. Underwater tunnels of even this shortened length will be challenging to construct, but the option has been developed for comparative purposes. Shifting the alignments closer to shore may also be considered in future studies.

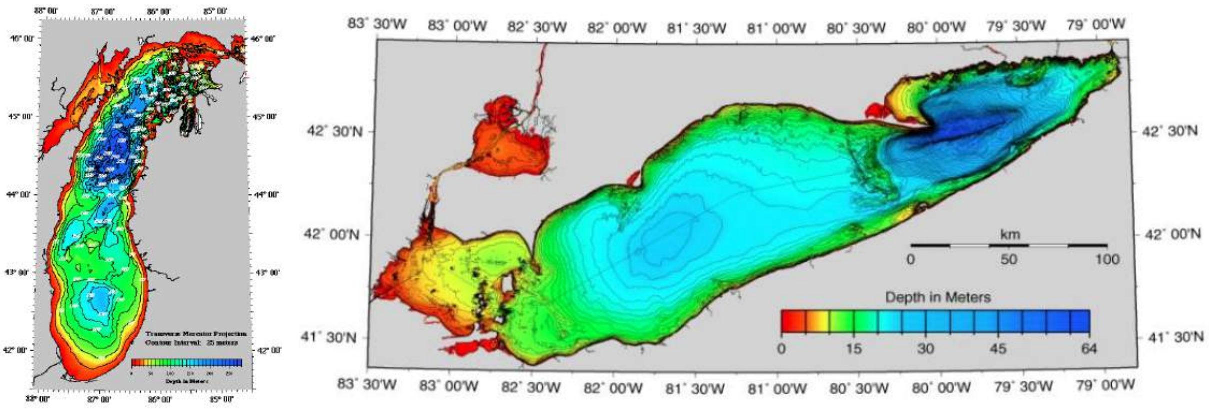
As shown in Exhibit 3-3, the alignment was extended on each end so it could still reach the downtown areas of Cleveland and Chicago. After this shift and extension, as compared to the original route, the length of the alignment was increased from 310.0 miles to 315.3 miles. This route shift negligibly increases the travel time from 0:30:24 to 0:31:52. For an apples-to-apples comparison, the option still serves only the endpoints, although as a result of the route shift, Cleveland Hopkins International Airport, Toledo and South Bend stops could be added. In fact, the Toledo to South Bend segment of the new straight line route could be utilized as a faster alternative to the Toll Road alignment without adding any underwater mileage. It is recommended that this be assessed in a future study.

Exhibit 3-3: The Straight Line Route

Downtown Cleveland, OH to Cleveland Hopkins Airport, OH – The interstate highway from downtown Cleveland is a very curvy urban freeway with a tight footprint. This geometry would severely constrain Hyperloop speeds, and the highway right-of-way has no land available for supporting the development of an elevated Hyperloop alignment. However, there is an opportunity to use existing very straight rail corridor from downtown to the airport. Although the final approach into downtown Cleveland may have to be tunneled, for much of the distance a cut-and-cover tunnel might be used. This would avoid having to bore a tunnel all the way from downtown Cleveland to the Cleveland Hopkins International Airport.

Cleveland Hopkins Airport to Toledo, OH – From Cleveland Hopkins Airport the alignment heads west towards Chicago which will bring it under the southern part of Lake Erie, 31 miles in a tunnel under the lakebed from Lorain past Sandusky to Port Clinton. As shown in Exhibit 3-4, this part of Lake Erie is quite shallow; only 15-60 feet deep near the southern shore of the lake. A tunnel of this length has been used for comparison purposes but because of the engineering considerations associated with an underwater tunnel of this length, it is not really being considered as a practical alternative. If the alignment could be shifted closer to shore in a future environmental study, it might be possible to develop it into a more practical option.

Exhibit 3-4: Depths of Lake Michigan and Lake Erie



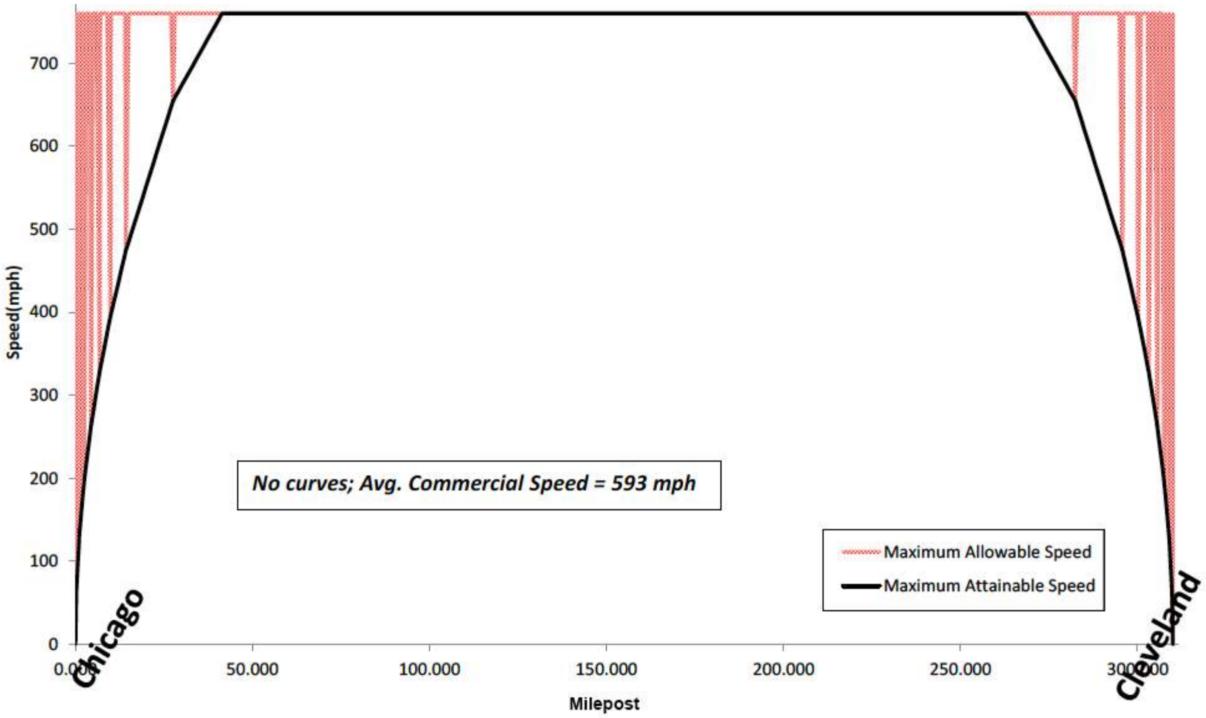
Toledo, OH to Michigan City, IN – From Toledo the alignment heads west to a point on the shore of Lake Michigan just north of Michigan City. Along the way, it passes through South Bend, IN.

Michigan City, IN to Hyde Park, IL – From here, the route heads 38 miles west across Lake Michigan to South Chicago. As shown in Exhibit 15, Lake Michigan's maximum depth of 924 feet occurs on the north end of the lake; but on the south end, the waters are is typically 100-150 feet deep. Once again, the construction of an underwater tunnel of this length poses a number of practical problems so the option might not really be feasible from an engineering perspective. However, it has been developed as an alternative here for the ability to compare the other routes with a hypothetical straight line alternative.

Hyde Park to Chicago, IL – From Hyde Park the alignment curves north approaching Block 37 (a potential downtown station site) under LaSalle Street. Most likely this entire segment will need to be in a bored tunnel.

As shown in the Speed Profile of Exhibit 3-5, the straight line option is very fast since it can maintain top speed for practically the whole time, just over 30 minutes. The capsule is able to accelerate to maximum speed and maintain this speed. It is also very energy efficient since it minimizes the need for acceleration and braking at intermediate points, both of which consume energy. The Straight Line route shows the benefits of keeping the Hyperloop alignment as straight as possible. This is a lesson that has broad applicability to the development of any Hyperloop alignment.

Exhibit 3-5: Speed Profile for Straight Line Alignment with 0.1G Acceleration: 0:31:52 time



3.3 Toll Road Route from Cleveland, OH to Chicago, IL

The original concept for the Toll Road Route was to utilize existing right-of-way, but the existing highway alignment proved to be too curvy for Hyperloop's use. As a result, a new approach generally following the corridor of the toll road was adopted. The proposed Toll Road alignment crosses the tollway on numerous occasions as it follows the general course of the highway. As shown in Exhibit 3-6, a viable Hyperloop alignment needs to straighten out numerous "zig zags" along the way. Exhibit 3-6 is simply illustrative of the issues involved in trying to use portions of highway right-of-way, and only reflects a representative route, not a final or selected route for the project.

Exhibit 3-6: Straightening the Corridor

This change in approach resulted in the development of an alternative that is considerably faster than the original toll road concept. The alignment has some gentle curves so it generally follows the tollway corridor and as a result

Hyperloop still cannot reach its maximum speed potential, but nonetheless the proposed system would be able to run faster than any existing surface transportation mode. This was regarded as satisfactory since it results in a conservative assessment of the alternative. It is quite likely that the alignment may be further improved when the project moves into the Environmental planning stage.

The toll road alignment has been extended east from the vicinity of the Cleveland Hopkins International Airport following the turnpike to Youngstown and ultimately to Pittsburgh, as shown in Exhibit 3-7. This Cleveland to Pittsburgh alternative is called the Cranberry Option since it passes through Cranberry as it approaches downtown Pittsburgh from the north. The Cleveland to Pittsburgh segment will be detailed in Section 3.4.

Downtown Cleveland, OH to Cleveland Hopkins Airport – The interstate highway from downtown Cleveland all the way to Elyria has the character of a very curvy urban freeway with a very tight footprint. This geometry is not conductive to the effective development of Hyperloop, and the highway right-of-way has no land available for supporting development of a surface Hyperloop alignment. However, there is a great opportunity to use existing very straight rail corridors for linking the urban core of Cleveland to the vicinity of the airport. The final approaches into the transit hub at the downtown Cleveland terminal tower as well as the transition between rail lines in Berea may have to be tunneled, for the rest of the way it may be possible to use cut-and-cover to avoid having to bore a tunnel all the way from downtown Cleveland to Elyria. At Berea, the representative route that has been developed for this assessment would switch from the CSX rail alignment to the Norfolk Southern lakefront alignment past the airport. (Other routes may be possible and can be more fully developed as needed in future work.) Cleveland Hopkins International Airport is located just west of the rail junction at Berea.

Cleveland Hopkins Airport to Elyria – The proposed Hyperloop alignment would follow the Norfolk Southern rail line past the airport until the corridor curves; at this point Hyperloop would continue straight under Elyria in a deep tunneled alignment to link the Norfolk Southern rail corridor with the Ohio Tollway corridor on the west side of Elyria.

Elyria to Perrysburg – From the outskirts of Elyria along the tollway to Perrysburg, the land is mostly rural, and the alignment would closely parallel the tollway but with a number of crossings as the highway zig-zags, but Hyperloop has to go straight. This again lends itself to consideration of cut-and-cover or elevated alignment.

Perrysburg through Toledo to Swanton – Beyond Perrysburg, the alignment crosses the Maumee River and passes through the southern part of the city of Toledo, passes by the north side of the Toledo Airport; then finally emerges at Swanton on the west side of the airport. There are no existing rights of way with acceptable geometry that could enable Hyperloop to get through this area. Most likely this entire stretch will need to be deep tunneled including underneath the Maumee River, thus avoiding both surface impacts and the need to bridge the Maumee River.

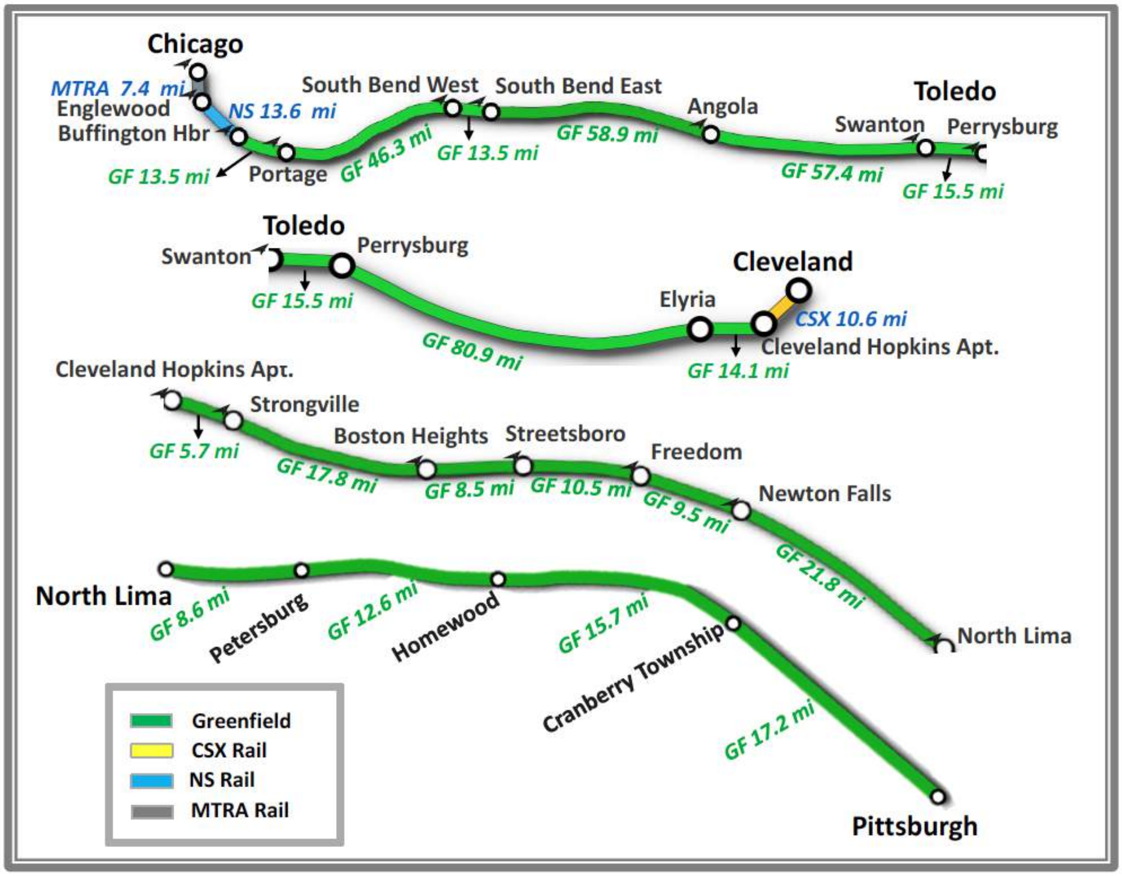
Swanton, OH through Angola, IN – Beyond Swanton to Angola, again the area is rural, and the alignment would closely parallel the tollway, lending itself to consideration of cut-and-cover or elevated alignment. A few miles of deep tunnel will be needed where the alignment passes directly through the town of Angola. The tollway passes north of the town, but the Hyperloop cannot follow the highway for geometric reasons.

Angola, IN to East South Bend, IN – From Angola, IN to South Bend, IN there is a fairly long segment where Hyperloop can closely parallel the tollway; although it has to cross from side to side as the tollway zig-zags. Hyperloop cannot follow the zig-zags without an unacceptable speed restriction. There is an opportunity in this stretch to utilize cut-and-cover or elevated construction; however, a key engineering issue will be to figure out the best construction method for passing over or under the highway as it zig-zags. The engineering issues need careful discussion both with Hyperloop's tunneling advisors as well as with the turnpike to develop the best approach for implementing a Hyperloop alignment that is closely intertwined with an existing freeway. This approach will be developed in more detail as part of the Environmental assessment and preliminary engineering for the project.

Through South Bend, IN – The proposed alignment passes straight through South Bend whereas the toll road loops to the south, and then comes back towards the north again east of the city. Hyperloop cannot follow the toll road through South Bend without a severe speed restriction. Therefore, it is assumed that the alignment will go straight across the city, connecting to the freeway corridor on each end, utilizing a bored tunnel to avoid surface impacts.

West South Bend, IN to Portage, IN – From the outskirts of South Bend to Portage, the land is more rural and lends itself to consideration of cut-and-cover or elevated construction.

Exhibit 3-7: The Toll Road Route (with Pittsburgh Extension via Cranberry)



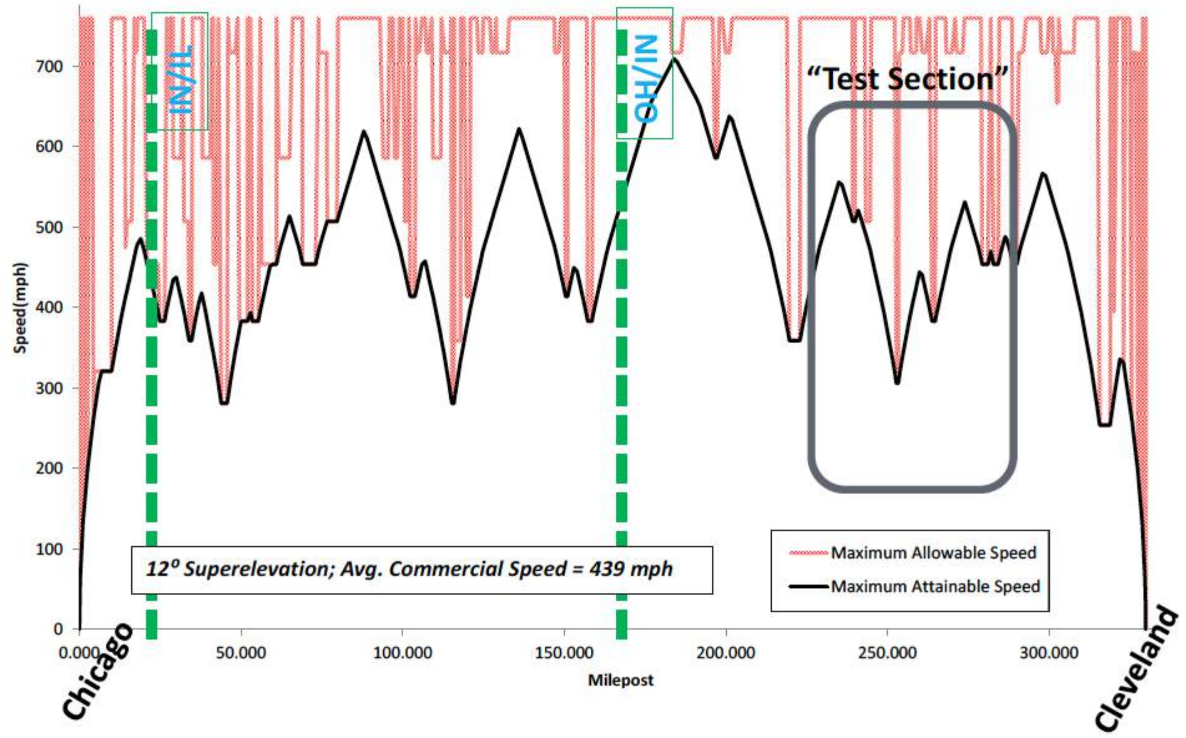
Portage, IN to Buffington Harbor, IN – Beyond Portage the alignment would follow CSS&SB rail through the north side of Gary. Beyond Gary it enters the Norfolk Southern rail alignment, skirting the steel mill property. Because of numerous obstacles on the surface, many of which will be difficult to avoid, this section will likely need to be in deep bored tunnel to avoid surface impacts.

Buffington Harbor, IN to Englewood, IL – Most likely this entire segment will need to be in deep bored tunnel because of numerous obstacles on the surface. The Indiana toll road alignment heads north generally following the Norfolk Southern rail line along the shore of Lake Michigan. It also parallels Interstate 90, but the highway along this section is very curvy urban freeway with a very tight footprint and has no land available for supporting the development of a surface alignment. The existing rail corridor has better geometry than does the highway and may even have some land, but it has numerous obstacles on the surface, many of which will be difficult to avoid. The Hyperloop alignment would tunnel directly under the Horseshoe Casino to ease a curve and would continue north along the Norfolk Southern rail corridor (but underground) all the way to South Chicago. The hybrid alternative also uses this same alignment to Buffington Harbor.

Englewood to Chicago, IL – At South Chicago the alignment would turn due north, paralleling the Metra rail line and I-90/I-94 highway to LaSalle Street station, then underneath LaSalle Street to Block 37. Most likely this entire segment will need to be in deep bored tunnel.

As shown in Exhibit 3-8, along the toll road alignment, even with the curves a Hyperloop vehicle could run from Chicago to Cleveland in under 50 minutes. The “Test Section” has better geometry than other parts of the Turnpike. Even so, the capsule never does reach its maximum rated speed of 760-mph because of geometric restrictions along the alignment. Nonetheless, with an average commercial speed of 439 mph, the option would still be much faster than any other known form of ground transportation.

Exhibit 3-8: Speed Profile for Toll Road Alignment with 0.1G Acceleration: 0:47:18 time



3.4 Toll Road Extension via Cranberry to Pittsburgh, PA

Cleveland has some very straight rail lines that approach the downtown along an east/west axis, paralleling Lake Erie. But for corridors that approach the city from other directions, rising terrain and river valleys impose significant geographic constraints on the development of routes. No rail lines or highways that enter the city from the south are straight enough to meet Hyperloop's geometric requirements. If it were desired to develop an effective entrance to Cleveland from the south, there is a high likelihood that only a deep tunneled alignment would be able to do this.

But even if a straight alignment from the south could be developed, the fact remains that any capsule approaching downtown Cleveland from the south would either have to make a 90^{0} left turn at the station or use a bypass routing, if it wanted to continue towards Chicago. A direct approach into downtown Cleveland from the south would only work well in conjunction with an alignment that continues due north under Lake Erie. Geometrically, a southern approach does not work well with either the Hybrid or Toll road alternatives, which enter Cleveland from the west.

As a result, for the development of an alignment option for extending the Chicago-Cleveland corridor to Youngstown, it makes more sense to connect with the existing alignment at Cleveland Hopkins Airport rather than in downtown Cleveland. As a result, what has been developed for Youngstown is an extension of the Chicago-Cleveland toll road alternative. The proposed Youngstown alignment diverges from the Norfolk Southern rail line near the airport and follows an electric utility corridor through Berea (Exhibit 3-9) so it can connect back to the Ohio Turnpike corridor.

As an extension of the Chicago-Cleveland route, the proposed Youngstown alignment would follow the turnpike From Berea all the way to Youngstown.

Exhibit 3-9: Electric Utility Corridor in Berea, OH

High-speed express connections at Berea are assumed for allowing capsules to go straight west onto the toll road route to Chicago, turn left to join the Hybrid route to Chicago, or turn right to go to Hopkins Airport and downtown Cleveland. The proposed connection would develop the ability for a capsule coming from Youngstown to make a high-speed connection towards either Cleveland or Chicago.

The highway alignment for interstate 76 / 279 running from the Youngstown station at North Lima to Pittsburgh is very curvy and thus the highway geometry is unacceptable for a Hyperloop route. However, a greenfield route has been developed that parallels the interstate at varying distances of up to about one mile away. To maintain the necessary geometry, the line would need to cross back and forth over the interstate at various points in order to maintain as straight a line as possible. This would allow the Hyperloop line from Youngstown to Pittsburgh to maintain an average speed above 300 miles per hour. However, the terrain from North Lima to the station at Pittsburgh is hilly to mountainous, particularly where the Hyperloop separate from the interstate right-of-way. Since Hyperloop cannot follow the vertical curves that would be needed for a following this terrain, it is assumed this stretch would need to be extensively tunneled.

Hopkins Airport through Berea back to the Ohio Turnpike at Strongsville – Diverging from the Norfolk Southern rail corridor at Olmsted Falls, the first part of this connection would clearly have to be tunneled; but once the electric utility corridor has been reached there is a good chance that a cut-and-cover tunnel alignment can be used. (It is unlikely that an elevated structure would be acceptable in close proximity to the high voltage electric transmission lines.)

Strongsville to Boston Heights, OH – From Strongsville to Richfield, the Hyperloop alignment parallels the tollway through a built-up area but not within the right-of-way. Beyond Richfield to Boston, the land is less developed, but the alignment encounters some terrain issues as it approaches and crosses the Cuyahoga River valley. The turnpike climbs to cross a high ridge at Boston Heights, which is crowned by a beautiful arch bridge carrying Olde 8 Road across the turnpike. Because of the development and the terrain, it is likely that a tunnel will be needed from

Strongsville all the way to Boston Heights. Most likely the alignment will pop out of the hillside to bridge over the Cuyahoga River valley, and then enter another tunnel under Boston Hill, on the east side of the Cuyahoga River valley. This area is a national park, which may impose restrictions on siting and construction.

Boston Heights through Hudson to Streetsboro, OH – From Boston Heights through Hudson the proposed Hyperloop would closely follow the Ohio Turnpike and may utilize cut-and-cover or elevated alignment. Beyond Hudson however it passes through a developed area in Streetsboro that will undoubtedly require a deep tunnel to avoid surface impacts.

Streetsboro to Freedom, OH – Beyond the developed area of Streetsboro the alignment emerges into a less developed area where there may be a possibility to use of cut-and-cover or elevated alignment.

Freedom to Newton Falls, OH – The toll road arcs north of the proposed Hyperloop alignment in this area making sharp turns in the vicinity of Braceville, and then passing the GM Lordstown auto assembly plant. However, Hyperloop cannot follow this geometry without a severe speed restriction. To ease these sharp curves a short-cut across the Camp Ravenna Joint Military base has been proposed. To avoid conflict with surface land uses a bored tunnel will probably be required in this segment.

Newton Falls to North Lima, OH – The proposed Hyperloop roughly follows the Ohio Turnpike in this area and it is likely that cut-and-cover or elevated alignment can be used, with the possible exception of the Canfield area where a tunnel will likely be required for avoiding surface impacts.

North Lima to Petersburg – The alignment starts out from North Lima paralleling interstate 76 for several miles, eventually crossing the interstate three times before reaching Petersburg. This segment of the route is characterized by light residential and commercial areas. The Hyperloop line also skirts along the edge of the Shelly Materials Inc. facility near Petersburg. At Petersburg, it runs through the edge of the town but avoids going through the center of town where there are a number of historic buildings.

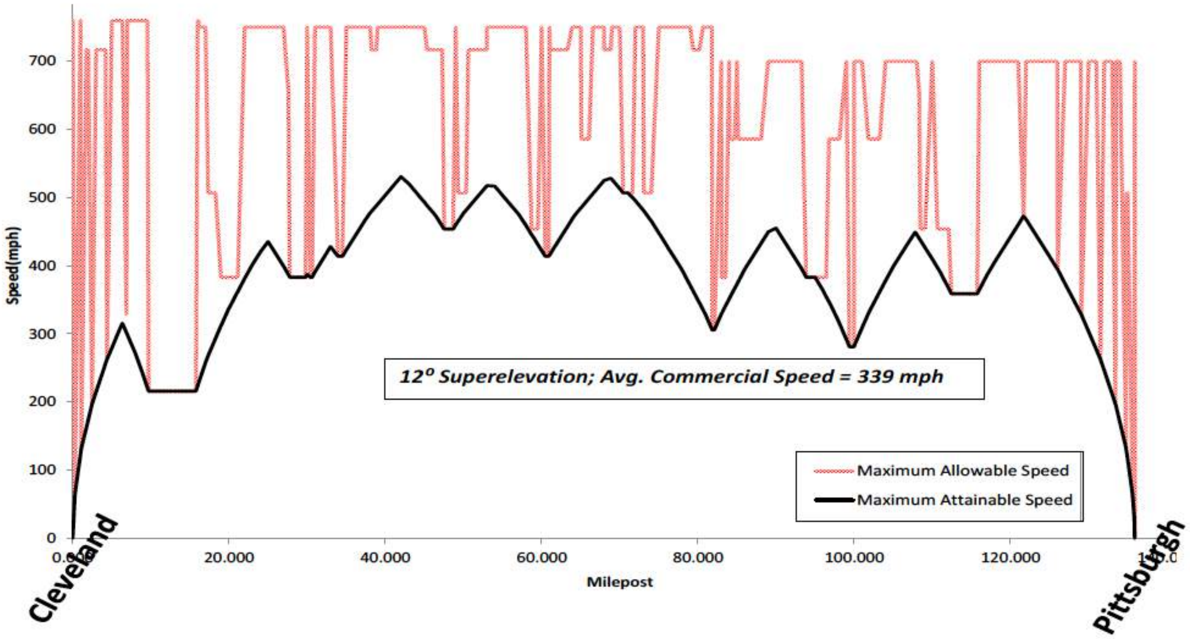
Petersburg to Homewood – From Petersburg, the alignment crosses the state line into Pennsylvania paralleling the interstate at a distance of up to a half a mile away, traveling mostly through farmlands, forests and wetlands. Along the way, it crosses under the Fort Wayne Rail Line twice near Rt. 168. It also crosses the interstate several times including also crossing the 375 interstate at Big Beaver. Near Homewood, the line passes under at least two light residential areas and past a light commercial area that includes the Holiday Inn hotel.

Homewood to Cranberry Township – From Homewood, the alignment crosses the Beaver River into an area of mixed topography characterized by open forests, residences and farmlands, including an agricultural easement near Melon Rd. The alignment also crosses the interstate twice before veering a distance of at least a mile away. Approaching Cranberry Township, the Hyperloop would tunnel underneath the Highlands Cranberry Golf course as the topography becomes increasingly residential and commercial. Through Cranberry Township, the Hyperloop closely follows the interstate in order to avoid significant commercial and residential impacts.

Cranberry Township to Pittsburgh – The topography from Cranberry Township to Pittsburgh is mountainous with significant residential and commercial development. It is apparent that this would necessitate a deep bore tunnel of approximately 16 miles to avoid impacts. From Cranberry Township, a tunneled alignment could follow a straight line to the route terminus in downtown Pittsburgh.

As shown in Exhibit 3-10, along the toll road alignment, even with some geometric constraints a Hyperloop vehicle could run from Cleveland to Pittsburgh in about 24 minutes. The vehicle never does reach its maximum rated speed of 760-mph because of geometric restrictions along the alignment. Nonetheless, with an average commercial speed of 339 mph, the option would still be much faster than any other known form of ground transportation.

Exhibit 3-10: Speed Profile for Cranberry Option to Pittsburgh with 0.1G Acceleration: 0:24:04 time

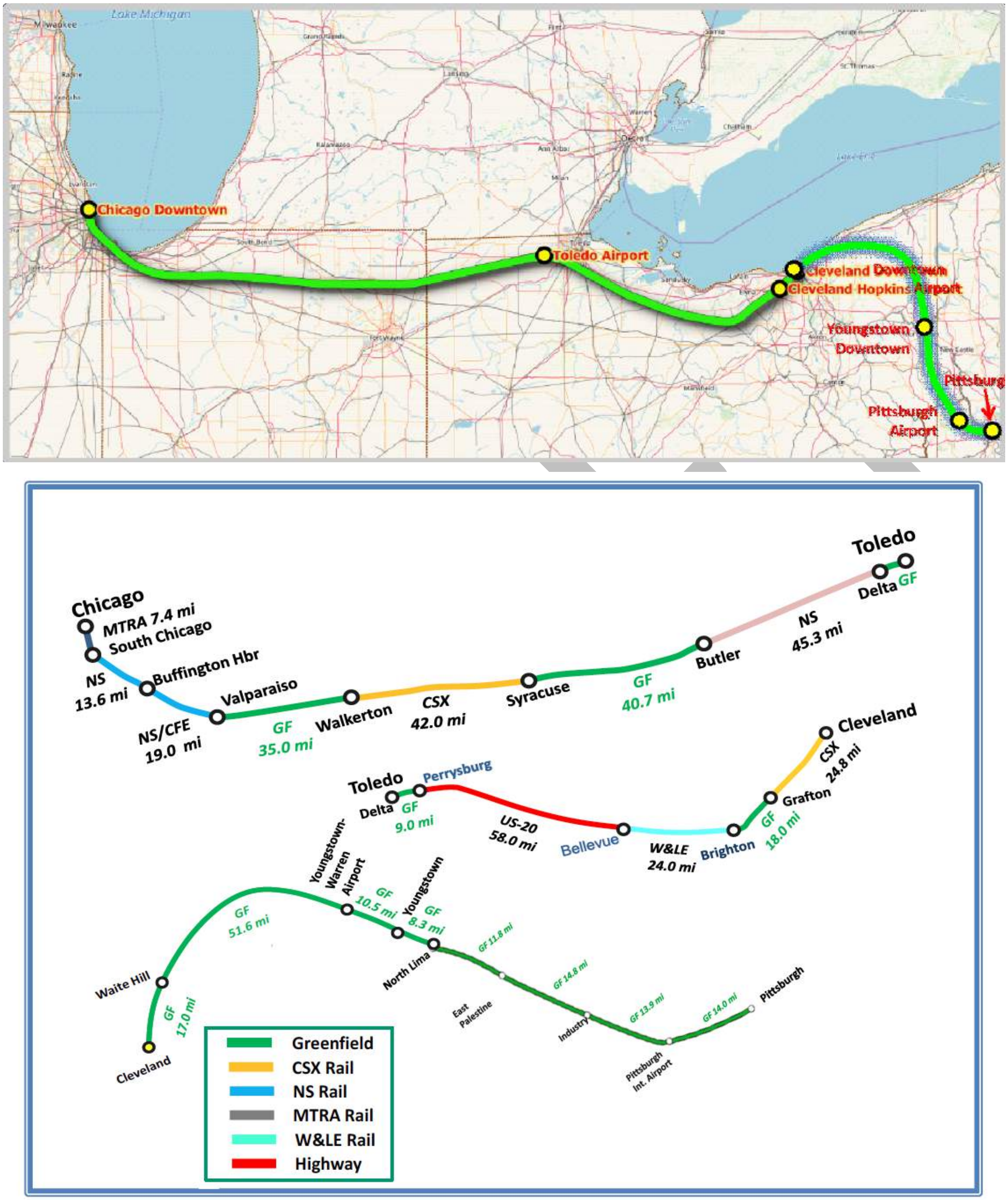


3.5 Hybrid Route from Cleveland, OH to Chicago, IL

The hybrid route is primarily based on the use of some very straight Midwestern rail lines (Exhibit 3-11) from Cleveland to Chicago, but also including a number of short interconnecting greenfield links. Some straight sections of highway right-of-way have also been included. Exhibit 3-12 shows the overall Hybrid route alignment, and a schematic representation of the proposed Hybrid alignment showing the various types of right-of-way that have been included. With extension of the corridor to Pittsburgh, a new alternative via Pittsburgh Airport was developed. However, the same route from Cleveland Hopkins Airport to downtown Pittsburgh that was developed for the toll road option was also assessed as an optional extension of the Hybrid route as well.

Exhibit 3-11: Typical Straight Midwestern Rail Alignment

Exhibit 3-12: The Hybrid Route (with Pittsburgh Extension via Airport)



Cleveland to Grafton, OH – The segment follows the CSX rail line from downtown Cleveland past Hopkins Airport all the way to Grafton. It would likely use either cut-and-cover or elevated alignment.

Grafton to Brighton, OH – The schematic indicates a greenfield or new right-of-way. In fact, a CSX rail line closely parallels in this stretch, so some of that rail right-of-way might be included. This segment includes a major curve at Wellington, which could be eased by developing a new alignment instead of following the rail line. This proposed greenfield segment would be new alignment constructed across open countryside and would likely use either cut-and-cover or elevated alignment.

Brighton to Bellevue, OH – From Brighton to Bellevue the schematic suggests that Hyperloop would share the W&LE railroad right-of-way; in fact, it may closely parallel portions of this rail alignment in some places, but the rail alignment is actually too curvy for Hyperloop's purposes, so this segment will in fact be a greenfield. This would be new alignment constructed across open countryside and would likely use either cut-and-cover or elevated alignment.

Bellevue to Perrysburg, OH – From Bellevue to Perrysburg, the alignment would follow the very straight US-20 highway as in Exhibit 3-13. Either cut-and-cover or elevated alignment would likely be used, but there are some engineering challenges at specific points that will need to be overcome to establish the feasibility of this alignment. If use of the highway right-of-way does not seem advantageous then this stretch could be shifted to a greenfield on new right-of-way.

Exhibit 3-13: Typical Very Straight Stretch of US-20

Perrysburg through Toledo to Delta, OH – There are no existing rights of way with acceptable geometry that could enable Hyperloop to get through this area. Most likely this entire stretch will need to be deep tunneled including a tunnel underneath the Maumee River.

Delta, OH to Butler, IN – This would follow a 41-mile long straight stretch of Norfolk Southern rail line. The rail line is double tracked and passes through several small towns along the way. There are instances where the alignment would encounter existing highway underpasses and overpasses along the rail line, as well as close-in industrial and some historic structures along the way. Either cut-and-cover or elevated alignment would likely be used in this stretch but there are some engineering challenges at specific points along the alignment that will need to be overcome.

Butler to Syracuse, IN – This segment would connect from the Norfolk Southern Chicago main line over to the CSX Garrett Subdivision rail line. This would be new alignment constructed across open countryside and would likely use either cut-and-cover or elevated alignment.

Syracuse to Walkerton, IN – This would follow a 35-mile long straight stretch of CSX rail line. The rail line is double tracked and passes through several small towns along the way. There are instances where the alignment would encounter existing highway underpasses and overpasses along the rail line, as well as close-in industrial and some historic structures along the way. Either cut-and-cover or elevated alignment would likely be used in this stretch but there are some engineering challenges at specific points along the alignment that will need to be overcome.

Walkerton to Valparaiso, IN – This segment would connect from the CSX Garrett Subdivision main line over to the CFE Fort Wayne Rail line. This would be new alignment constructed across open countryside and would likely use either cut-and-cover or elevated alignment. Because of significant urban development, the alignment in Valparaiso would need to enter a deep tunnel underneath the town. Two rail lines also pass through Valparaiso, but both have sharp curves which are not acceptable for a Hyperloop alignment.

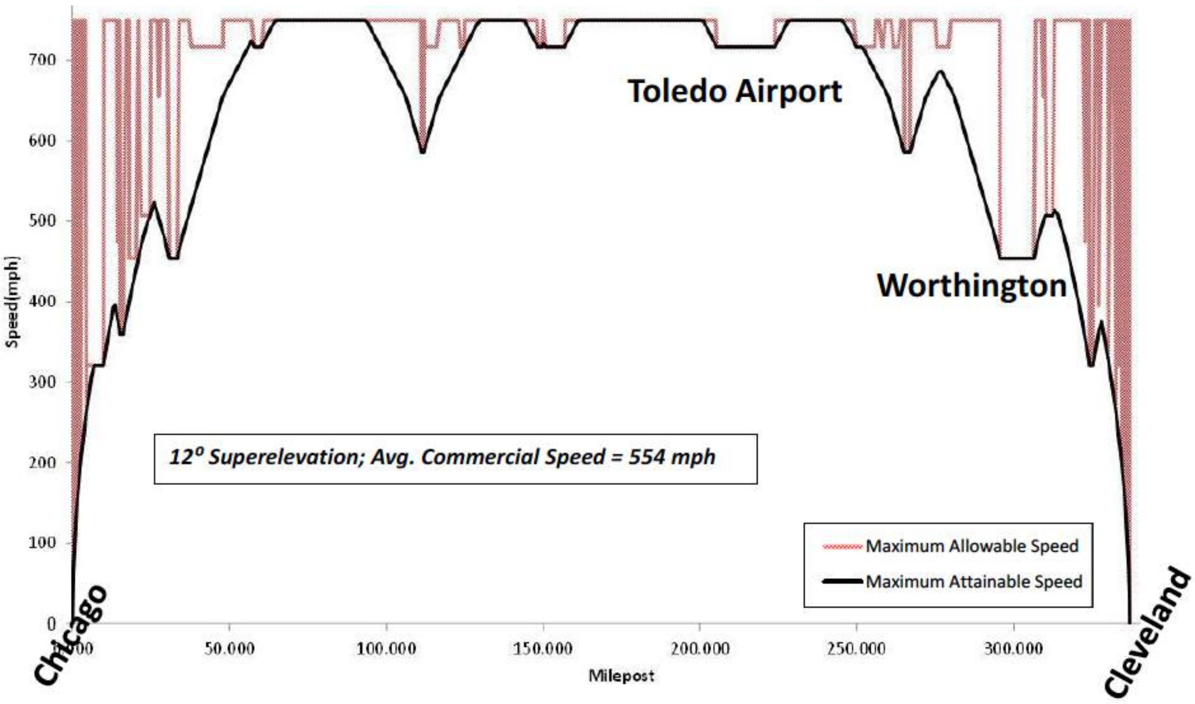
Valparaiso to Buffington Harbor, IN – Beyond Valparaiso to Buffington Harbor, the alignment would follow the NS/CFE rail right-of-way. CSX owns the track along the north side of the alignment, which is leased to CFE. NS owns the track along the south side of the alignment but has the right to use either track. The rail right-of-way in this area is straight and fairly wide, so there is a good possibility to use either cut-and-cover or elevated alignment.

Buffington Harbor, IN to Englewood, IL – From Buffington Harbor to South Chicago, the hybrid and toll road would follow the same alignment along the NS corridor, as already described. Most likely this entire segment will need to be in deep bored tunnel.

Englewood to Chicago, IL – From South Chicago to South Chicago, the hybrid and toll road would follow the same alignment paralleling the Metra rail line and I-90/I-94 highway, as already described. Most likely this entire segment will need to be in deep bored tunnel.

As shown in Exhibit 3-14, the Hybrid alignment is quite fast, a Hyperloop vehicle could run from Chicago to Cleveland in about 37 minutes and with recent curve modifications will be able to reach its maximum rated speed of 760-mph over a significant portion of the alignment.

Exhibit 3-14: Speed Profile for Hybrid Alignment with 0.1G Acceleration: 0:36:28 time



3.6 Hybrid Extension via Airport to Pittsburgh, PA

An additional route alternative from Cleveland to Pittsburgh has been developed. As already noted, the original alternative following the Toll Road via Cranberry diverged from the main line at Cleveland Hopkins International Airport (Berea) so that the route into downtown Cleveland became a branch line. The objectives for developing this second alternative were to:

- Develop the route as an extension from downtown Cleveland so that the downtown area would not be left at the end of a branch line.
- Allow for high-speed movements of through Hyperloop capsules through downtown Cleveland. This means that the main corridor would have to continue straight through the station and could not make any sharp turns or changes of direction at the station itself.
- Add service to downtown Youngstown and Pittsburgh Airport.

Taken together, the combination of these requirements would mandate an alignment that tunnels northeast under Cleveland and gradually arcs towards the southeast, using a very gentle curve so as not to impose a speed restriction. The alignment passes through downtown Youngstown where it can have a station stop; crosses the Ohio Tollway and Cranberry alignment at North Lima; and continues on a south-southeasterly heading to the Pittsburgh International Airport. The alignment turns east underneath the airport and continues to a station in downtown Pittsburgh, entering the city from the west rather than from the north, as the Cranberry option does.

As such the proposed Airport option is completely separate from and independent of the Cranberry option, although it could be possible to interconnect and mix-and-match these options where they cross at North Lima.

Downtown Cleveland to Waite Hill, OH – The Airport extension to Pittsburgh starts at the downtown Cleveland Hyperloop station and continues northeasterly (without any change in direction) to allow through capsules to run through the station without having to slow down or stop. However, within the first 5-10 miles the alignment needs to start arcing south (turning right) towards Youngstown. This would result in the development of 5-10 miles of alignment actually heading northeast towards Buffalo before the curve starts. This section of fairly straight alignment might be incorporated in the future into a possible extension to Buffalo and New York state. Due to development in suburban Cleveland the alignment must remain in tunnel until it reaches the fringe of the urbanized area at Waite Hill.

Waite Hill to Youngstown-Warren Airport, OH – Beyond Waite Hill some portions of the alignment may be able to come to grade or be constructed in cut-and-cover rather than bored tunnel across some sections of relatively flat farmland. Approximately 39 miles east of Waite Hill the alignment must tunnel underneath a shallow arm of Mosquito Creek lake, it must do this to maintain a smooth arc for turning south towards Youngstown. It continues in a gentle turn until it tunnels directly underneath the Youngstown-Warren Airport, which happens to lie along the direct path towards downtown Youngstown. No station has been provided for the Youngstown-Warren Airport in this assessment, although if it were decided to further develop this option, a station could be added there in the future.

Youngstown-Warren Airport to Downtown Youngstown, OH – Beyond Youngstown-Warren Airport the alignment passes through a suburban area on the northern outskirts of Youngstown. To avoid surface impacts most of this alignment would probably have to be tunneled. A station would be developed on the south side of the Youngstown Central Business district.

Downtown Youngstown to North Lima, OH – From downtown Youngstown the alignment would continue to North Lima, where it would cross the Ohio Turnpike as well as the proposed Cranberry alignment following the turnpike. Along the way it would have to tunnel for a short distance underneath Evans Lake. Also, if desired the Cranberry and Airport alignments could be interconnected at North Lima, so it could be possible to mix-and-match the alternatives either east or west of this point.

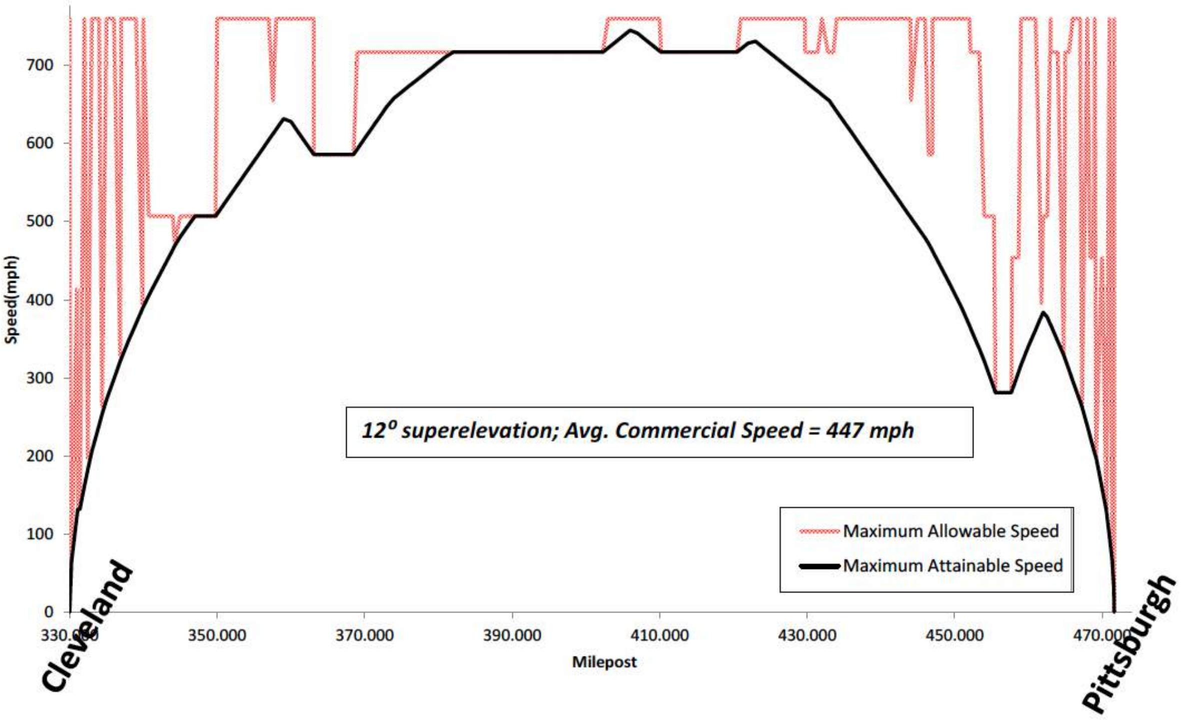
North Lima to East Palestine, OH – The town of East Palestine lies along the route to Pittsburgh Airport, about 12 miles south of North Lima. It will be necessary to tunnel underneath the town to avoid surface impacts.

East Palestine, OH to Pittsburgh International Airport, PA – Beyond East Palestine the topography starts to become mountainous, so there will be very little opportunity for the alignment to come to grade. The alignment tunnels underneath the Ohio River at Monaca, PA about 36 miles downstream from Pittsburgh, just south of the Montgomery Dam. It tunnels directly underneath the Pittsburgh International Airport and curves east towards downtown Pittsburgh.

Pittsburgh International Airport to Downtown Pittsburgh, PA – The proposed alignment continues east in a tunnel crossing under the Monongahela River at the confluence of the three rivers; entering downtown Pittsburgh on an east-west alignment, rather than entering from the north as the Cranberry option does.

As shown in Exhibit 3-15, the Airport alignment has excellent geometry so that a Hyperloop vehicle could run from Cleveland to Pittsburgh in about 19 minutes. It would have an average commercial speed of 447 mph which is substantially faster than that of the Cranberry alignment.

Exhibit 3-15: Speed Profile Airport Option to Pittsburgh with 0.1G Acceleration: 0:18:58 time



3.7 Running Time Results

The running times resulting from the LOCOMOTICN^{TM} simulation reflect theoretical unimpeded performance capabilities of the vehicles and guideways and do not include any slack time, delay for capacity, or allowances for station docking/undocking or maneuvering times. Realistic timetables need to include some allowance for a short delay waiting for a slot to accelerate into the tube, and for other possible delays, e.g. docking at the destination station, and so for this reason it is proposed to add 5 minutes to the unimpeded travel times.

Exhibits 3-16, 3-17 and 3-18 summarize the station-to-station travel times for each of the three route alternatives. Exhibits 3-18 and 3-19 are two-part exhibits, giving results for both the Cranberry and Airport route alternatives.

- The first part of each exhibit shows unimpeded track times in HH:MM:SS format, based on a direct point-to-point LOCOMOTION^{TM} simulation of travel time. The simulations are based on an acceleration limit of 0.1 G.
- The second part of each exhibit shows scheduled point-to-point times, including the 5-minute additive. These times are rounded to the nearest whole minute.

Exhibit 3-16: Point to Point Travel Times (in Minutes) for the Straight Line Option

LOCOMOTION^{TM} TPC Time

	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend	Chicago
Youngstown						
Cleveland	-					
Hopkins Apt	-	-				
Toledo	-	-	-			
South Bend	-	-	-	-		
Chicago	-	0:31:52	-	-	-	

Schedule Time with 5-min Slack

	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend	Chicago
Youngstown						
Cleveland	-					
Hopkins Apt	-	-				
Toledo	-	-	-			
South Bend	-	-	-	-		
Chicago	-	37	-	-	-	

Exhibit 3-17: Point to Point Travel Times (in Minutes) for the Toll Road Option

(a) Via Cranberry

	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	0:12:05					
Cleveland	0:24:04	0:16:07				
Hopkins Apt	0:21:56	0:13:59	0:04:31			
Toledo	0:35:48	0:27:51	0:19:51	0:17:41		
South Bend	0:51:13	0:43:16	0:38:55	0:33:06	0:19:27	
Chicago	1:03:15	0:55:18	0:47:18	0:45:08	0:31:29	0:16:04

LOCOMOTION^{TM} TPC Time

	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	17					
Cleveland	29	21				
Hopkins Apt	27	19	10			
Toledo	41	33	25	23		
South Bend	56	48	44	38	24	
Chicago	68	60	52	50	36	21

Schedule Time with 5-min Slack

(b) Via Airport

	Pittsburgh	PBG Airport	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
PBG Airport	0:05:34						
Youngstown	0:11:50	0:09:29					
Cleveland	0:18:58	0:16:40	0:12:40				
Hopkins Apt	0:20:07	0:17:49	0:13:49	0:04:31			
Toledo	0:33:59	0:31:41	0:27:41	0:19:51	0:17:41		
South Bend	0:49:24	0:47:06	0:43:06	0:38:55	0:33:06	0:19:27	
Chicago	1:01:26	0:59:08	0:55:08	0:47:18	0:45:08	0:31:29	0:16:04

LOCOMOTION^{TM} TPC Time

	Pittsburgh	PBG Airport	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
PBG Airport	11						
Youngstown	17	14					
Cleveland	24	22	18				
Hopkins Apt	25	23	19	10			
Toledo	39	37	33	25	23		
South Bend	54	52	48	44	38	24	
Chicago	66	64	60	52	50	36	21

Schedule Time for COMPASS^{TM} with 5-min Slack

Exhibit 3-18: Point to Point Travel Times (in Minutes) for the Hybrid Option

(a) Via Cranberry

	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	0:12:05					
Cleveland	0:24:04	0:16:07				
Hopkins Apt	0:21:56	0:13:59	0:04:31			
Toledo	0:34:37	0:26:40	0:17:56	0:16:25		
South Bend	-	-	-	-	-	
Chicago	0:52:59	0:45:02	0:36:38	0:34:56	0:24:37	-

LOCOMOTION™ TPC Time

	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	17					
Cleveland	29	21				
Hopkins Apt	27	19	10			
Toledo	40	32	23	21		
South Bend	-	-	-	-	-	
Chicago	58	50	42	40	30	-

Schedule Time with 5-min Slack

(b) Via Airport

	Pittsburgh	PBG Airport	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
PBG Airport	0:05:34						
Youngstown	0:11:50	0:09:29					
Cleveland	0:18:58	0:16:40	0:12:40				
Hopkins Apt	0:20:07	0:17:49	0:13:49	0:04:31			
Toledo	0:32:48	0:30:30	0:26:30	0:17:56	0:16:25		
South Bend	-	-	-	-	-	-	
Chicago	0:51:58	0:49:40	0:45:40	0:36:38	0:34:56	0:24:37	-

LOCOMOTION™ TPC Time

	Pittsburgh	PBG Airport	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
PBG Airport	11						
Youngstown	17	14					
Cleveland	24	22	18				
Hopkins Apt	25	23	19	10			
Toledo	38	36	32	23	21		
South Bend	-	-	-	-	-	-	
Chicago	57	55	51	42	40	30	-

Schedule Time for COMPASS™ with 5-min Slack

3.8 Summary

This Chapter has proposed three different conceptual representative route alternatives for development of a Hyperloop connecting Cleveland, OH to Chicago, IL and Pittsburgh, PA. The routes vary in terms of their development strategy.

- The Straight Line route develops the shortest possible connection with the best possible geometry regardless of cost. This alignment was shifted south so that it directly connects Cleveland with Chicago. Along the way the shifted alignment passes through both Toledo and South Bend.
- The Toll Road route follows the path of the Ohio and Indiana turnpikes and along the way it is able to add service to both Toledo and South Bend. The alignment as developed here has a number of curves as it attempts to follow the general course of the toll road. As a result, it is the slowest of the three options. However, many of these curves would likely be straightened out in a subsequent environmental study.
- The Hybrid route tries to make the greatest use of existing straight rail and highway alignments for minimizing the need for easements. The ability to use existing alignments is very situational and specific to individual corridors. The alignment that was assessed here includes Toledo but bypasses South Bend. It is possible that other alignment options that effectively use existing rights of way may be identified in future studies. Additional engineering and environmental assessment are needed to fully understand all the advantages versus risks and costs associated with reuse of existing rights of way for Hyperloop.

The travel time projections that were developed by this study do reflect the geometric characteristics of the routes at their current level of development. These will all likely be further refined in future studies. But it is important to note that all of the times are quite similar and are all much faster than any existing transportation alternative: as a result, there are only very minor differences in the ridership of the three route alternatives.

Since all three alternatives are very fast, travel time is not a strong differentiating factor. Rather, the ridership and financial results are going to be more strongly influenced by the markets served, both endpoint and intermediate. As a result, the strategy for optimizing financial and economic returns has to ensure that the Hyperloop network connects and serves as many traffic generators as possible.

Chapter 4

Corridor Demographics, Socioeconomic & Transportation Databases

Summary

This chapter describes the zone system, socioeconomic data, transportation networks, origin-destination data, and stated preference survey data upon which the hyperloop ridership forecast will be based.

4.1 Introduction

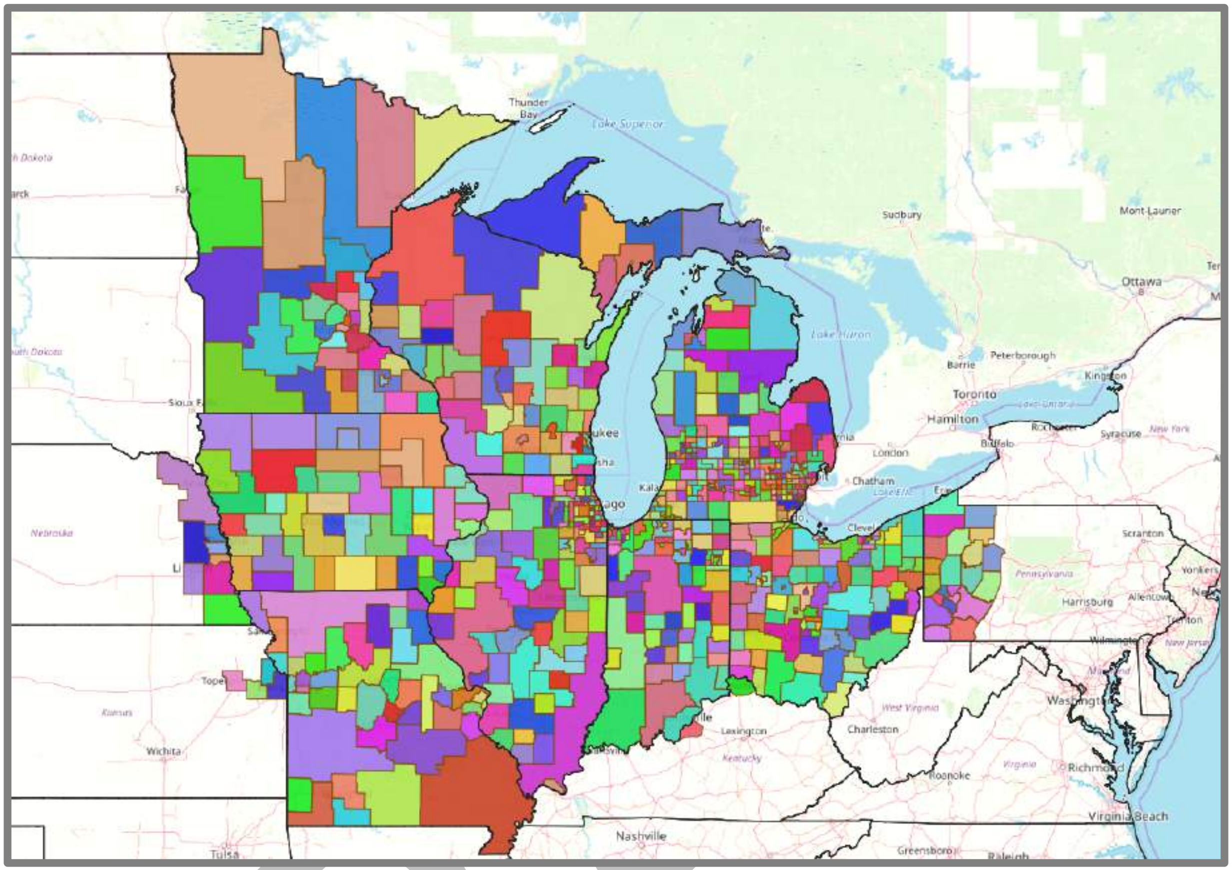
To better represent the travel market that covers a large area, the study area is divided into zones to reflect the characteristics of travelers and trips of different origin-destination pairs which are the basic building blocks of the COMPASS™ Model. In order to forecast the future Total Travel Demand in the corridor, base year and future socioeconomic data for each zone are developed and inputted into the model. All databases: socioeconomic characteristics, transportation networks, and trips, are also built at the zonal level. In particular, the main drivers of growth in the travel market, namely, population, employment and income, are developed at the zonal level. The COMPASS™ Model then processes the data and outputs the Total Travel Demand Forecast including hyperloop ridership and revenue results, at the zonal level.

In order to understand the level of intercity and interurban travel in a corridor, a zone system is defined that allows the number of trips between one location (zone) and another (zone) to be measured. As such, the system provides a representation of the travel occurring from zone origins to zone destinations for any given market in the corridor (e.g., business, social travel). For Hyperloop planning, most rural zones are represented by larger areas. However, where it was important to identify more refined trip origins and destinations in urban areas, finer zones are typically used. The Total Travel Demand Model forecasts the total number of trip origins and destinations, purpose and by zone pair. A separate hierarchical mode split model is used to estimate individual mode market shares.

4.2 Zone System

For the Hyperloop study, an effective zone system was developed based on aggregation of the census tracts and traffic analysis zones (TAZs) of local transportation planning agencies. Exhibit 4-1 shows the zone system for study area.

Exhibit 4-1: Study Area Zone System



In order to understand the level of intercity and interurban travel in a corridor, a zone system is defined that allows the number of trips between one location (zone) and another (zone) to be measured. As such, the system provides a representation of the travel occurring from zone origins to zone destinations for any given market in the corridor (e.g., business, commuter, social travel). For public transportation planning, most rural zones are represented by larger areas. However, where it was important to identify more refined trip origins and destinations in urban areas, finer zones are typically used. These zones are usually based on urban model zones (TAZ) that are developed by Metropolitan Planning Organizations (MPOs) for planning purposes. The Travel Demand Model forecasts the total number of trip origins and destinations by mode, purpose and by zone pair.

4.3 Socioeconomic Database Development

In order to estimate the base and future travel market total demand, the travel demand forecasting model requires base year estimates and future growth forecasts for three socioeconomic variables of population, employment and per capita income for each of the zones in the study area. A socioeconomic database was established for the base year (2018) and for each of the forecast years (2020-2050).

The data was developed at five-year intervals using the most recent data collected from the following sources:

- U.S. Census Bureau

- American Community Survey 5-Year Estimates
- U.S. Bureau of Economic Analysis
- Woods & Poole Economics
- Metropolitan Planning Organizations (MPOs) in the corridor

4.4 Base Year Transportation Database Development

To understand the existing travel market, the base year existing travel networks and travel demand by mode and travel purpose in the corridor were developed. The travel modes include auto, bus, air, and rail. The travel purposes are business, commuter, and other (social, tourist, etc.) trips. This separation of business and non-business trips is important since business trips are paid for by firms who have a willingness to use more expensive options and have a high value of time (VOT), while non -business trips are paid for by individuals who look for less expensive travel choices and who typically have a much lower value of time (VOT). In addition to calculating values of time (VOTs) for different travel purposes and travel modes, generalized costs for values of frequency (VOFs) and values of access time (VOAs) are also developed for the corridor.

4.4.1 Base Year (2018) Transportation Networks

In transportation analysis, travel desirability/utility is measured in terms of travel cost and travel time. These variables are incorporated into the basic transportation network elements that provide by mode the connections from any origin zone to any destination zone. Correct representation of the existing and proposed travel services is vital for accurate travel forecasting. Basic network elements are called nodes and links that connect nodes and centroids. Each travel mode or travel option consists of a database comprised of zones and stations that are represented by nodes, and existing connections or links between them in the study area. Each node and link is assigned a set of travel attributes (time and cost). The network data assembled for the study included the following attributes for all the zone pairs.

For public travel modes (air, Hyperloop, rail, bus):

- Access/egress times and costs (e.g., travel time to a station, time/cost of parking, time walking from a station, etc.)
- Waiting at terminal and delay times
- In-vehicle travel times
- Number of interchanges and connection times
- Fares
- Frequency of service

This data is derived from public information sources such as timetables, schedules and published information.

For private mode (auto):

- Travel time, including rest time
- Travel cost (vehicle operating cost)
- Tolls
- Parking Cost
- Vehicle occupancy

The highway network was developed to reflect the major highway segments within the study area. The sources for building the highway network in the study area are as follows:

- State and Local Departments of Transportation highway databases
- The Bureau of Transportation Statistics HPMS (Highway Performance Monitoring System) database

The highway network of the study area coded in COMPASS™ is shown in Exhibit 4-2. Three networks were developed: one for business travel, one for commuter travel, and one for other travel purposes (social, tourist and etc.)

Exhibit 4-2: COMPASS™ Highway Network for the Study Area

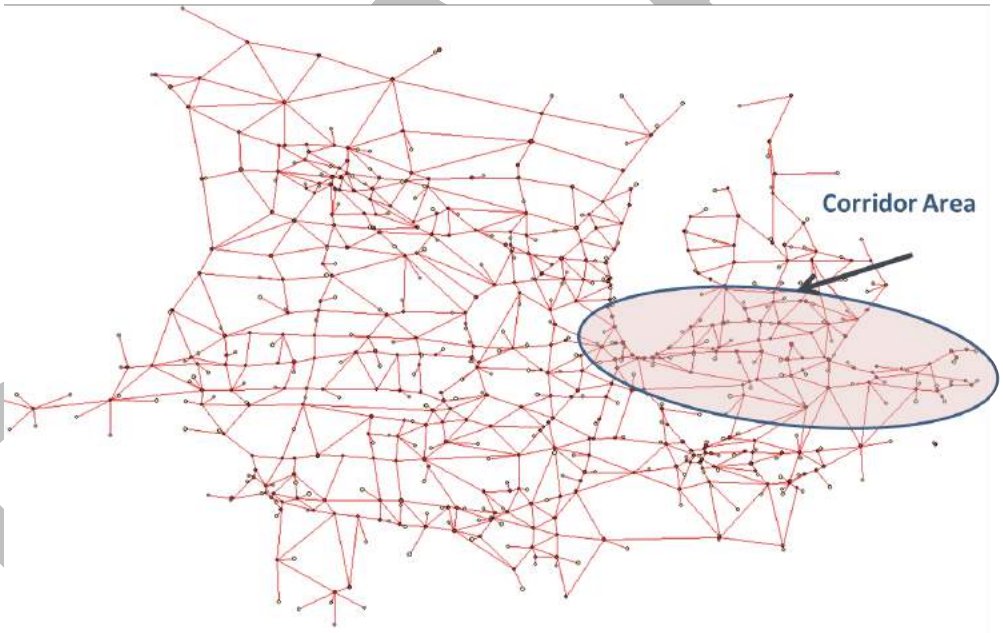
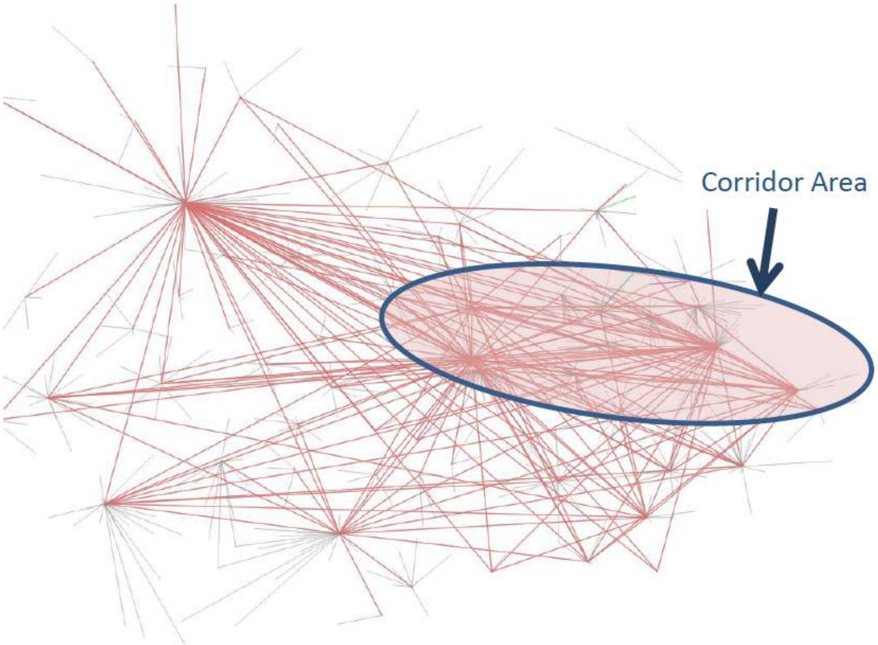


Exhibit 4-3 shows the air network coded in COMPASS™. Again, networks for business travel, commuter travel and non-business travel were developed

Exhibit 4-3: COMPASS™ Air Network for Study Area



Bus travel data of travel time, fares, and frequencies were obtained from official schedules of Greyhound. Exhibit 4-4 shows the bus network of the study area coded in COMPASS™.

Exhibit 4-4: COMPASS™ Bus Network for the Study Area

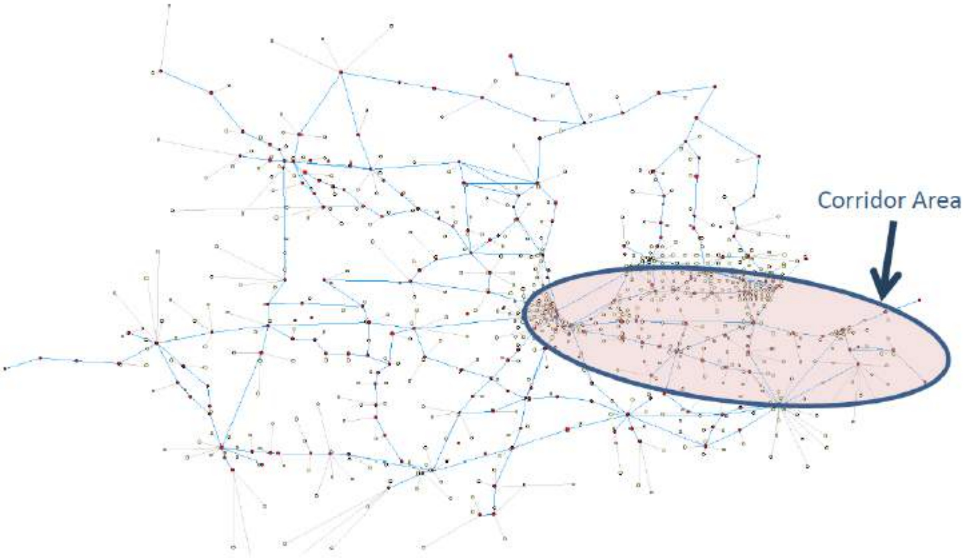
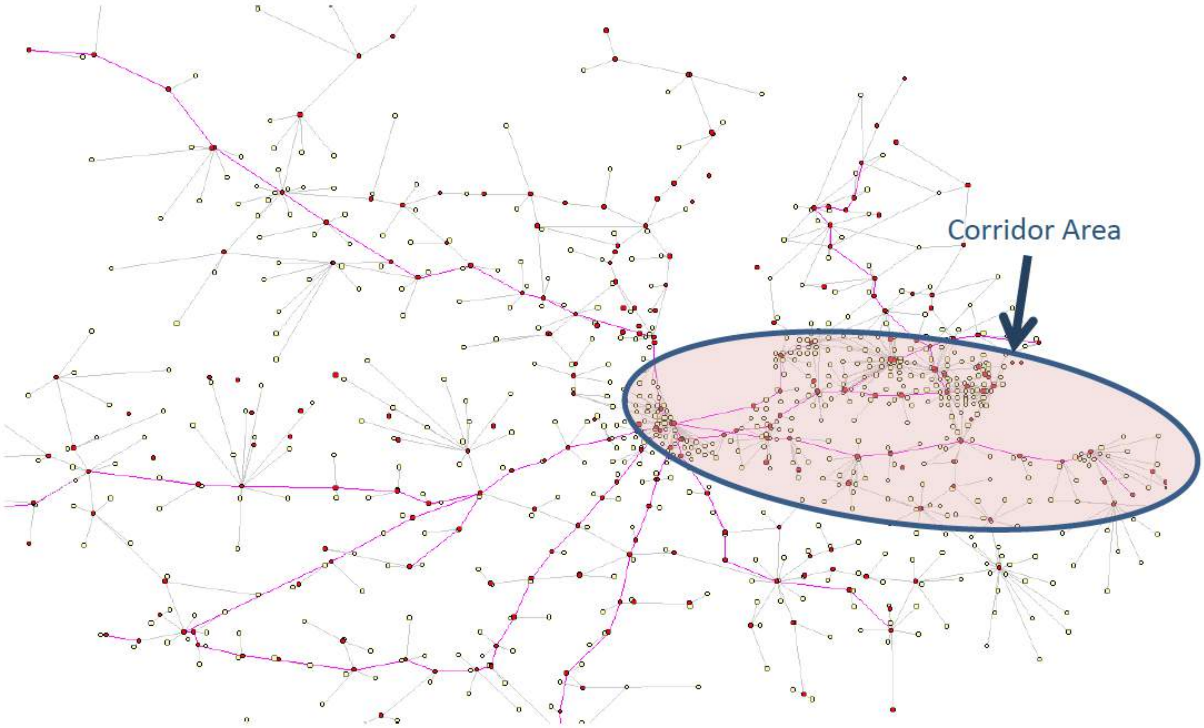


Exhibit 4-5 shows the rail network of the study area coded in COMPASS™.

Exhibit 4-5: COMPASS™ Rail Network for the Study Area



4.4.2 Origin-Destination Trip Database

The multi-modal intercity travel analyses model requires the collection of base origin-destination (O-D) trip data describing annual personal trips between zone pairs. For each O-D zone pair, the annual personal trips are identified by mode (auto, air, rail and bus) and by trip purpose. Because the goal of the study is to evaluate intercity travel, the O-D data collected for the model reflects travel between zones (i.e., between counties, neighboring states and major urban areas) rather than within zones.

TEMS extracted, aggregated and validated data from a number of sources in order to estimate base travel between origin-destination pairs. The main data sources for the origin-destination trips in the study are:

- Metropolitan Planning Organizations
- Bureau of Transportation Statistics
- Midwest Regional Rail Initiative Study Travel Survey
- FAA 10% Air Ticket Sample

The travel demand forecast model requires the base trip information for all modes by purpose between each zone pair. In some cases, this can be achieved directly from the data sources, while in other cases the data providers only have origin-destination trip information at an aggregated level (e.g., AADT data, station-to-station trip and bus station volume data). Where that is the case, a data enhancement process of trip simulation and access/egress simulation needed to be conducted to estimate the zone-to-zone trip volume. The data enhancement process is shown in Exhibit 4-6.

For the auto mode, the quality of the origin-destination trip data was validated by comparing it to AADTs and traffic counts on major highways and adjustments have been made when necessary. For public travel modes, the origin-destination trip data was validated by examining FAA Airport-to-Airport 10% sample data, rail Amtrak passenger train loadings and, bus intercity station volumes and segment loadings.

Exhibit 4-6: Zone-to-Zone Origin-Destination Trip Matrix Generation and Validation

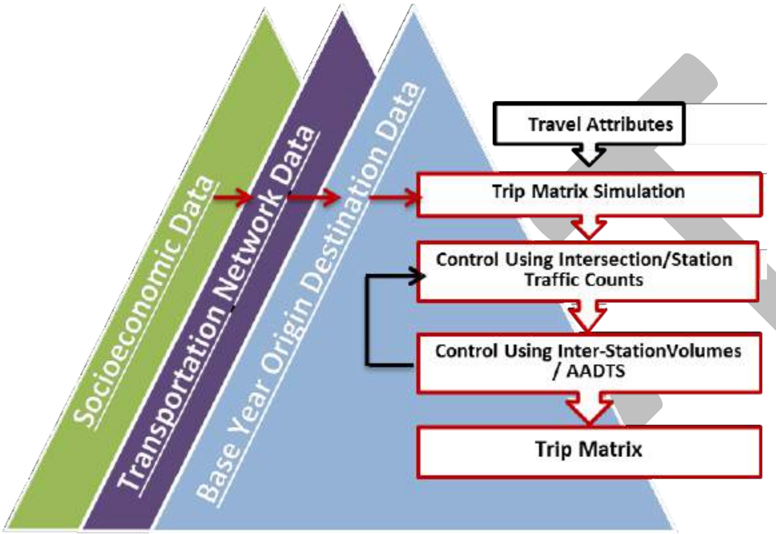
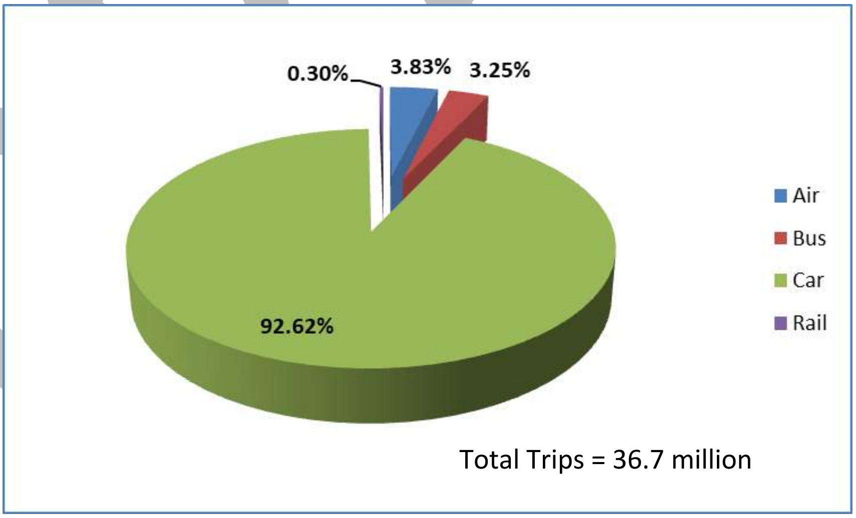


Exhibit 4-11 shows the base 2018 study area travel market share of air, bus, rail, and auto modes. The total intercity and interurban travel demand in the corridor is 36.7 million in 2018. It can be seen that auto mode dominates the travel market with more than 92 percent of market share. Public modes have seven percent of travel market share.

Exhibit 4-7: Base Year Travel Market (2018)



4.4.3 Values of Time, Values of Frequency, and Values of Access Times

Generalized cost of travel between two zones estimates the quality of services of the transportation system on the overall level of trip making. Generalized Cost includes all the factors that are key to an individual's travel decision (such as travel time, fare, frequency) that are all included in the Generalized Cost equation for the COMPASS™ Model. Generalized Cost is typically defined in travel time (i.e., minutes) rather than cost (i.e., dollars). Costs are converted to time by applying appropriate conversion factors such as Value of Time, derived from Stated Preference Surveys. The generalized cost (GC) of travel between zones i and j for mode m and trip purpose p is defined as follows:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} + \frac{VOF_{mp} * OH}{VOT_{mp} * F_{ijm}}$$

Where,

TT_{ijm} = Travel Time between zones i and j for mode m (in-vehicle time + station wait time + connection time + access/egress time), with waiting, connect and access/egress time multiplied by a factor (waiting and connect time factors is 1.8, access/egress factors were determined by ratios from the Michigan Detroit-Chicago SP survey) to account for the additional disutility felt by travelers for these activities.

TC_{ijmp} = Travel Cost between zones i and j for mode m and trip purpose p (fare + access/egress cost for public modes, operating costs for auto)

VOT_{mp} = Value of Time for mode m and trip purpose p

VOF_{mp} = Value of Frequency for mode m and trip purpose p

F_{ijm} = Frequency in departures per week between zones i and j for mode m

OH = Operating hours per week (sum of hours between the first and last services of each day)

Value of Time (VOT) is the amount of money (dollars/hour) an individual is willing to pay to save a specified amount of travel time, the Value of Frequency (VOF) is the amount of money (dollars/hour) an individual is willing to pay to reduce the time between departures when traveling on public transportation. Access/Egress time is weighted higher than in-vehicle time in generalized costs calculation, and its weight is derived from value of access stated preference surveys. Station wait time is the time spent at the station before departure and after arrival. On trips with connections, there would be additional wait times incurred at the connecting station. Wait times are weighted higher than in-vehicle time in the generalized cost formula to reflect their higher disutility as found in previous stated preference surveys.

Exhibits 4-8 and 4-9 show the values of time and values of frequency from the TEMS Stated Preference Travel Survey in Midwest regions.

Exhibit 4-8: VOT values by Mode and Purpose of Travel ($2018/hour)

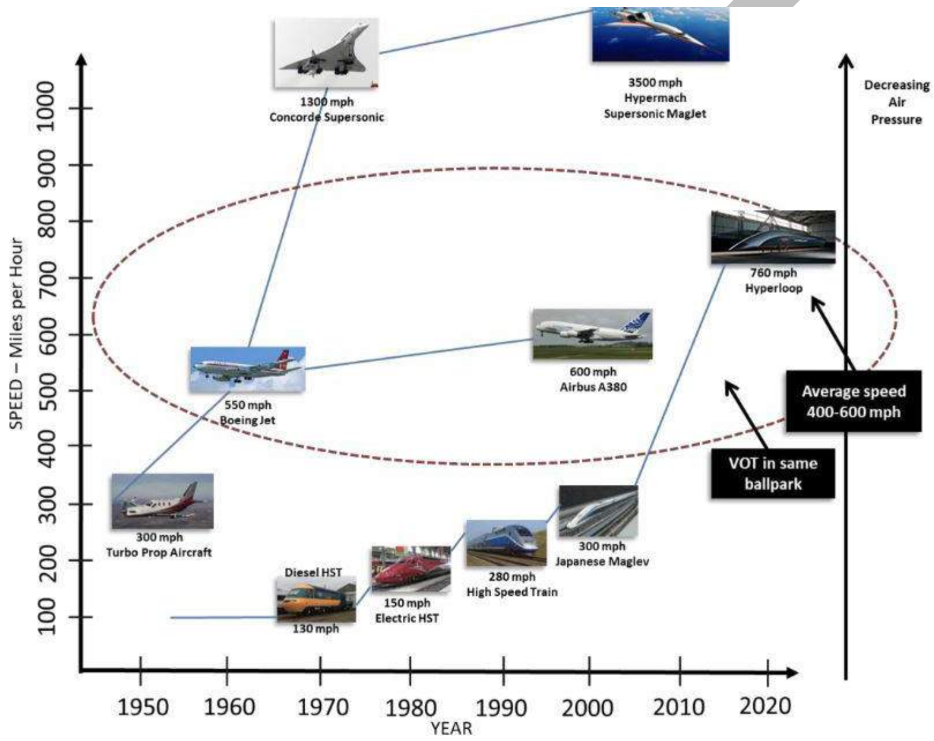
Value of Time (VOT)	Business	Non-business
Auto	$30.06	$27.11
Bus	$22.35	$16.46
Rail	$42.87	$30.68
Air	$54.06	$42.97

Exhibit 4-9: VOF values by Mode and Purpose of Travel ($2018/hour)

Value of Frequency (VOF)	Business	Non-business
Bus	$5.82	$5.78
Rail	$11.42	$9.66
Air	$27.99	$20.14

It should be noted that the highest values of time (VOTs) are related to the fastest modes, with air being higher than rail and auto, which are higher than the bus. As a result, since Hyperloop offers speeds equivalent or better than air, it is likely that Hyperloop with have VOTs as high as or higher than air. However, a conservative assumption was made that the values of time and frequency should only be equivalent to air. Exhibit 4-10 shows how Hyperloop speed compares with current commercial aircraft speed.

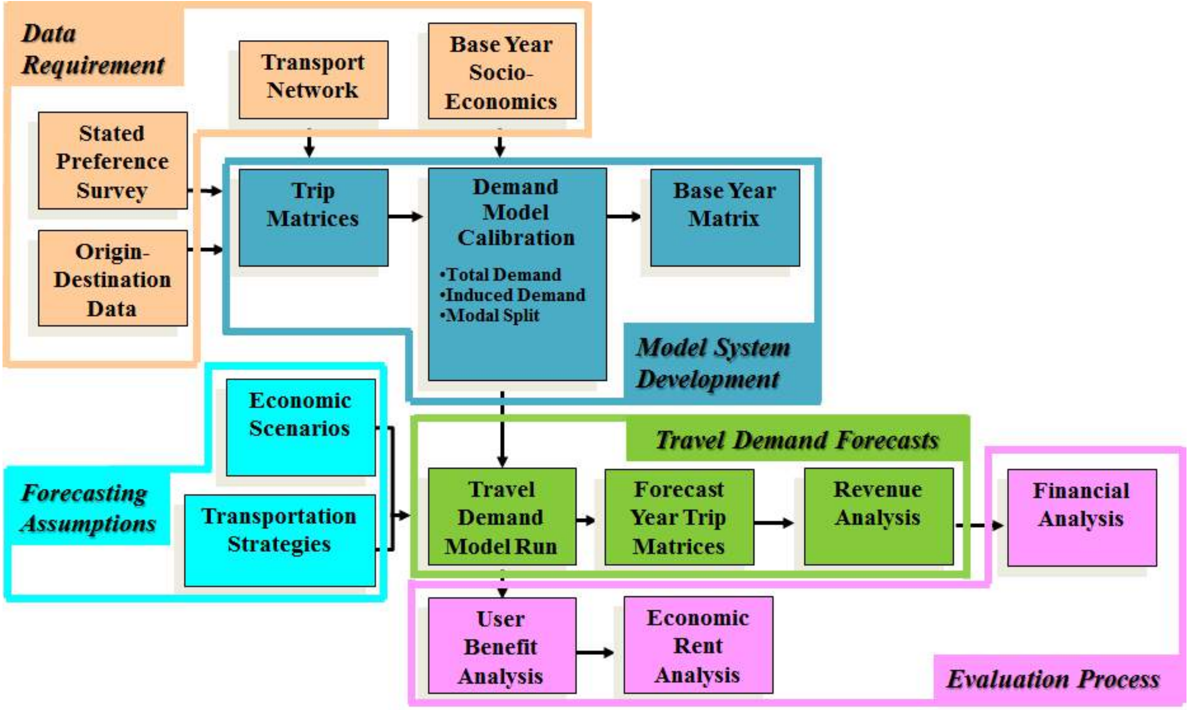
Exhibit 4-10: Hyperloop Should Have VOT's Similar to Commercial Aircraft



4.4.4 Basic Structure of the COMPASS™ Travel Market Forecast Model

For the purpose of this study ridership and revenue forecasts were made using the COMPASS™ Travel Demand Model. The COMPASS™ Multimodal Demand Forecasting Model is a flexible demand forecasting tool used to compare and evaluate alternative Hyperloop routes and service scenarios. It is particularly useful in assessing the introduction or expansion of public transportation modes such as air, bus, high-speed rail, and Hyperloop into markets. Exhibit 4-11 shows the structure and working process of the COMPASS™ Model. As shown, the inputs to the COMPASS™ Model are base and proposed transportation networks, base and projected socioeconomic data, value of time and value of frequency from Stated Preference surveys, and base year travel data obtained from government agencies and transportation service operators.

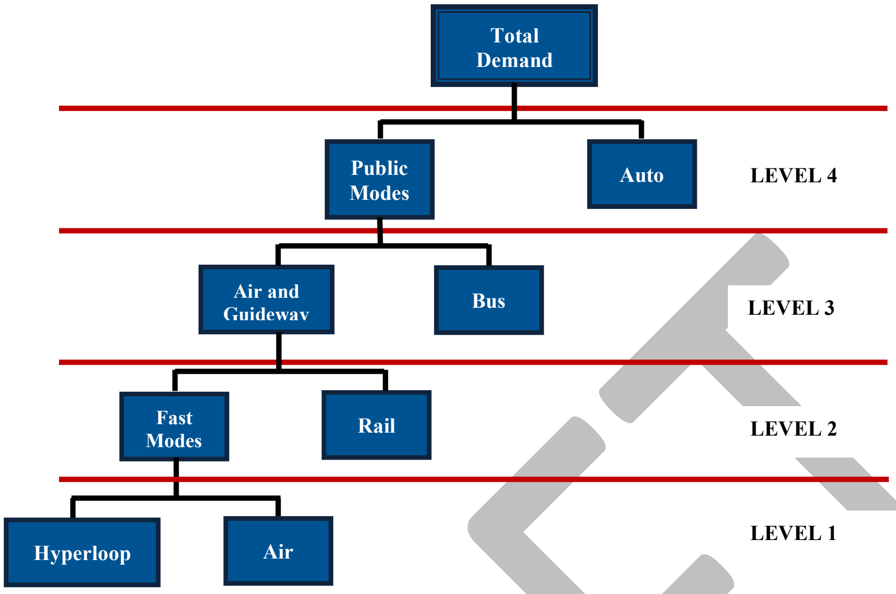
Exhibit 4-11: Structure of the COMPASS™ Model



The COMPASS™ Model structure incorporates two principal models: a Total Demand Model and a Hierarchical Modal Split Model. These two models are calibrated separately. In each case, the models are calibrated for origin-destination trip making in the study area. The Total Demand Model provides a mechanism for replicating and forecasting the total travel market. The total number of trips between any two zones for all modes of travel is a function of (1) the socioeconomic characteristics of the two zones and (2) the travel quality provided by the overall transportation system that exists (or will exist) between the two zones. Typical socioeconomic variables include population, employment and income. The quality of the transportation system is measured in terms of total travel time and travel cost by all modes, and the induced demand is estimated by considering the change in quality of travel offered by all modes.

The role of the COMPASS™ Modal Split Model is to estimate relative modal shares of travel given the estimation of the total market by the Total Demand Model. The relative modal shares are derived by comparing the relative levels of service (as estimated by generalized costs) offered by each of the travel modes. Four levels of binary choice were used in this study (see Exhibit 4-12). The first level separates Hyperloop and Air which are fast transportation services. The second level separates Fast services from Rail services. The third level of the hierarchy separates Fast services and Rail service form Bus. The fourth level separates auto travel with its perceived spontaneous frequency, low access/egress times, and highly personalized characteristics, from public modes (i.e., Hyperloop, Air, Rail, and Bus). The model forecasts changes in ridership, revenue and market share based on changes in travel time, frequency and cost for each mode as measured by the generalized costs for each mode.

Exhibit 4-12: Hierarchical Structure of the Modal Split Model



A key element in evaluating Hyperloop service is the comprehensive assessment of the travel market in the corridor under study, and how well the proposed Hyperloop service might perform in that market. For the purpose of this study, this assessment was accomplished using the following process:

- Building the zone system that enables a more detailed analysis of the origin-destination travel market and the development of base year and future socioeconomic data for each zone.
- Compiling information on the service levels (times, fares, frequency, costs) in the corridor for auto, air, bus, rail, and the proposed Hyperloop travel.
- Identifying and quantifying factors that influence travel choices, including values of time, frequency and access/egress time.
- Developing strategies that quantify how travel conditions will change, including future gas price, future vehicle fuel efficiency improvement, and highway congestion.
- Developing and calibrating total travel demand and modal split models for travel demand forecasting.
- Forecasting travel, including total demand and modal shares.

Chapter 5
Hyperloop Ridership and Revenue

Summary

This chapter develops the market analysis of the potential for Hyperloop ridership, presenting the Travel Demand Forecast for the Hyperloop corridor including ridership, revenue and market share results.

5.1 Future Travel Market Strategies

In order to forecast the future potential for rail ridership, consideration has to be given to how future travel markets will be impacted by changing transportation conditions. The critical factors that will change future travel conditions include fuel prices, vehicle fuel efficiency, as well as highway traffic congestion. In addition, the forecasts need to assess the different levels of rail service that might be developed, and how it will compete with auto, air, and bus markets. This includes planned transportation improvements that are relevant to the different route options.

5.1.1 Fuel Price Forecasts

One of the important factors in the future attractiveness of Hyperloop is fuel price. Exhibit 5-1 shows the Energy Information Agency (EIA)[3] projection of crude oil prices for three oil price cases: namely a high world oil price case that is for an aggressive oil price forecast; a reference world oil price case that is moderate and is also known as the central case forecast; and a conservative low world oil price case. In this study, the reference case oil price projection is used to estimate transportation cost in future travel market. The EIA reference case forecast suggests that crude oil prices are expected to be $70 per barrel in 2020 and will increase to $114 per barrel in 2050.

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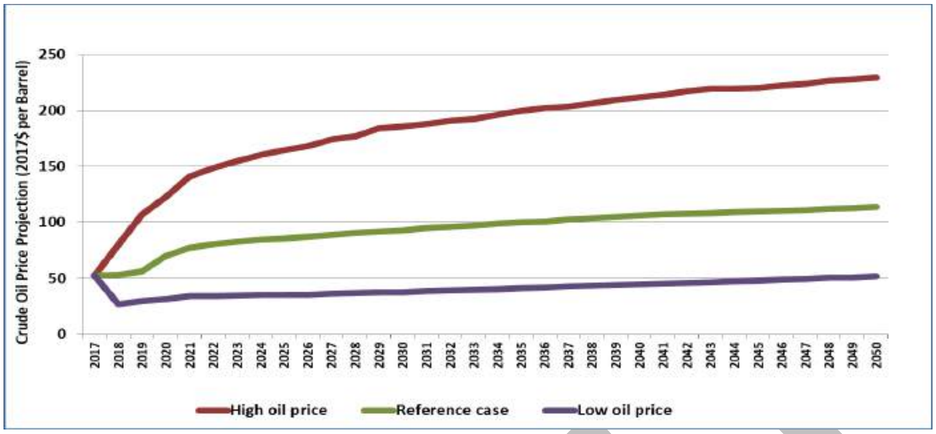
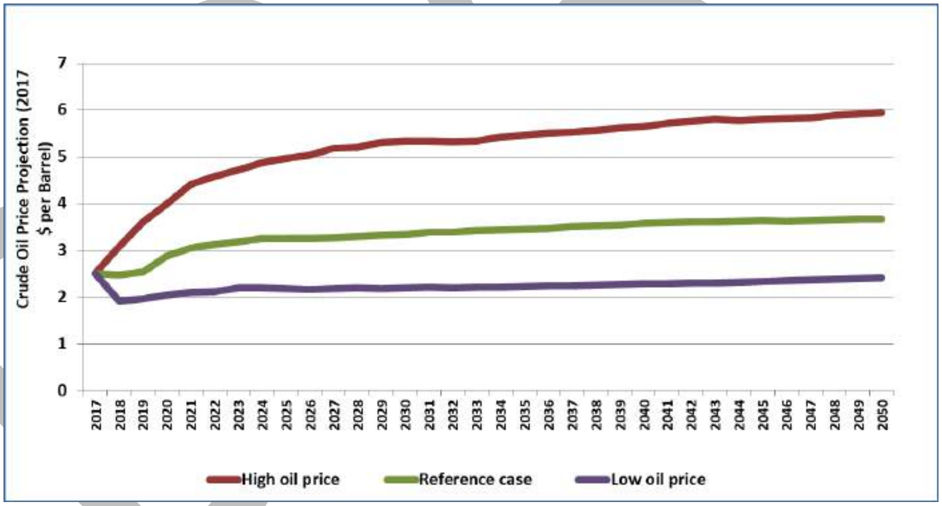
[3] EIA periodically updates historical and projected oil prices at www.eia.gov/forecasts/aeo/tables_ref.cfm

Exhibit 5-1: 2018 Crude Oil Price Forecast by EIA



EIA has also developed a future retail gasoline price forecast, which is shown in Exhibit 5-2. The implication of this is a reference case gasoline price of $2.88 per gallon in 2020, with a high case price of $4 per gallon, and a low case price of $2.03 per gallon. The reference case gasoline price will increase to $3.67 per gallon in 2050. The impact of rising energy prices will clearly impact the competition between the modes of travel in the corridor. Typically rising energy and therefore gas prices will most severely impact auto travel followed by air mode, bus mode and finally rail. High-Speed Ground Transportation is very fuel efficient and its market share typically increases with rising energy and gas prices. For example, increasing energy prices have been very instrumental in the recent dramatic increases in Amtrak traffic.

Exhibit 5-2: U.S. Retail Gasoline Prices Forecast by EIA



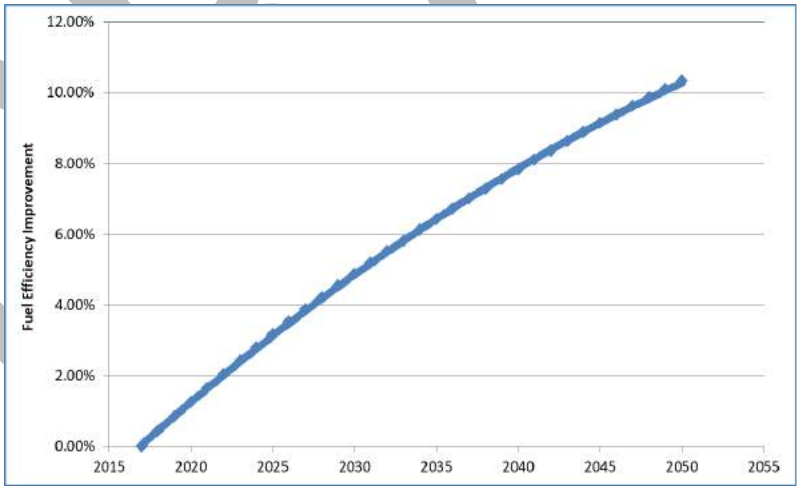
5.1.2 Vehicle Fuel Efficiency Forecasts

Future improvement in automobile technology is likely to reduce the impact of high gas prices on automobile fuel cost with better fuel efficiency. The Oak Ridge National Laboratory (ORNL) Center for Transportation Analysis (CTA) provides historical automobile highway energy usage in BTU (British thermal unit) per vehicle-mile data for automobiles since 1970 (Exhibit 5-3).

Exhibit 5-3: ORNL Historical Highway Automobile Energy Intensities Data

Exhibit 5-3 shows the historical highway automobile energy intensities from 1970 to 2012. It can be seen that automobile fuel efficiency has been improving gradually during the past few decades, but the improvement perhaps surprisingly has slowed down in recent years. Future automobile fuel efficiency improvement was projected by TEMS as shown in Exhibit 5-4. The TEMS forecast reflects the actual performance of the vehicle fleet, which is much lower and slower to be implemented than the regulated Corporate Average Fuel Economy (CAFE) standards for new cars. The auto fleet simply changes at a much slower pace than the standards for new cars. It was based on the historical automobile fuel efficiency data. The TEMS forecast shows a slow but consistent increase in car fuel efficiency to 2050, and beyond. It shows that the automobile fleet fuel efficiency is expected to improve by more than 10 percent by 2050 as compared to fuel efficiency of today.

Exhibit 5-4: Auto Fuel Efficiency Improvement Projections



5.1.3 Highway Traffic Congestion

The average annual auto travel time growth in the corridor was estimated with the projected highway traffic volume data and the Bureau of Public Roads (BPR) function that can be used to calculate travel time growth with increased traffic volumes:

$$T_f = T_b * [1 + \alpha * \left(\frac{V}{C}\right)^{\beta}]$$

where

T_f is future travel time,

T_b is highway Average travel time,

V is traffic volume,

C is highway Average capacity,

α is a calibrated coefficient (0.56), it describes the volume of traffic required for the capacity of the road to become limited by traffic (i.e., when it will begin to slow traffic speed)

β is a calibrated coefficient (3.6), it describes the slope or sensitivity of the highway to congestion once capacity becomes limited (i.e., how quickly traffic speed falls as traffic increases).

The projected travel times were calculated by computing travel time on each segment of the highway route between two cities. The key assumptions are as follows:

α = 0.56

β = 3.6

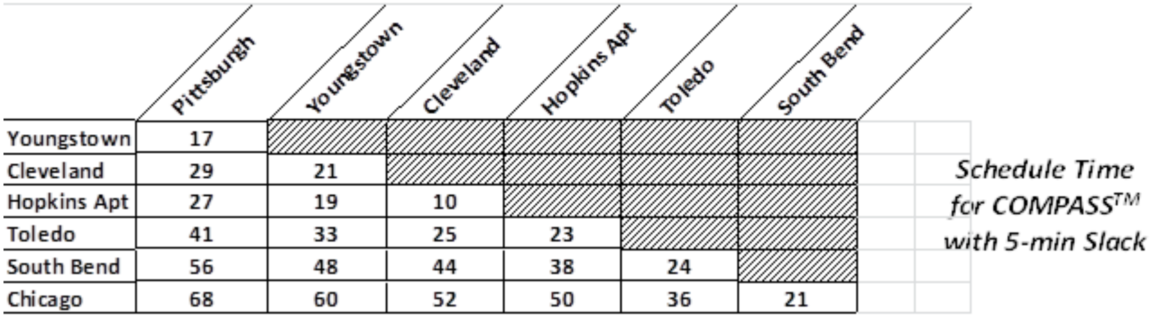
The above two coefficients are from the Highway Capacity Manual, they determine how traffic volume will affect travel speed.

5.1.4 Hyperloop Scenarios

For Hyperloop ridership and revenue forecast, two Hyperloop scenarios were used in the forecast modeling procedure. The two scenarios are Turnpike and Hybrid options; the running times for these two scenarios are shown in Exhibit 5-5.

Exhibit 5-5: Hyperloop Travel Times

Hyperloop Travel Times of Turnpike Option



	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	17	▨	▨	▨	▨	▨
Cleveland	29	21	▨	▨	▨	▨
Hopkins Apt	27	19	10	▨	▨	▨
Toledo	41	33	25	23	▨	▨
South Bend	56	48	44	38	24	▨
Chicago	68	60	52	50	36	21

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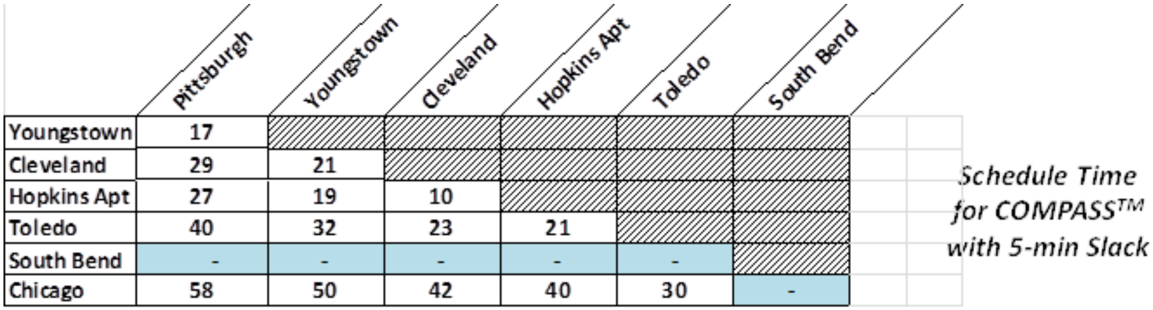
Hyperloop Travel Times of Hybrid Option



	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	17					
Cleveland	29	21				
Hopkins Apt	27	19	10			
Toledo	40	32	23	21		
South Bend	-	-	-	-	-	
Chicago	58	50	42	40	30	-

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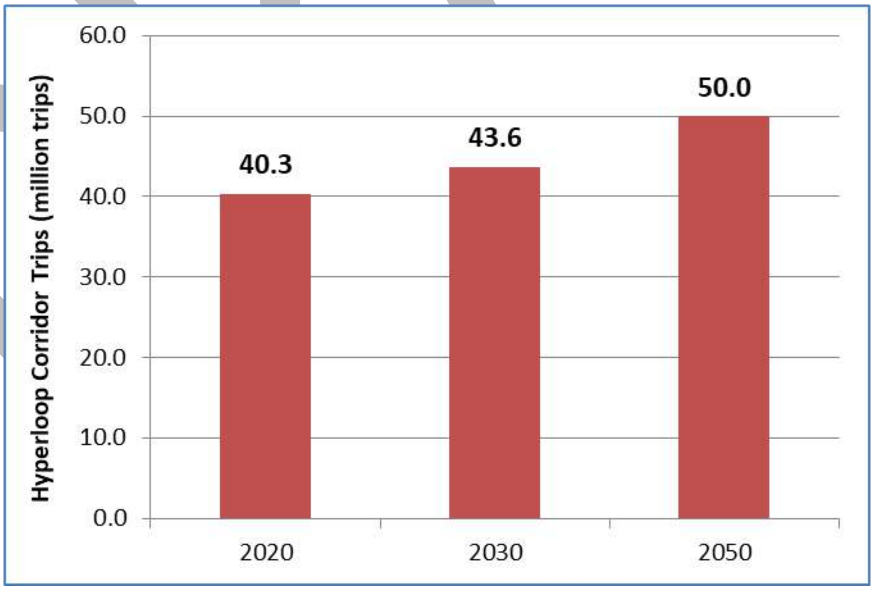
5.2 The Travel Demand Forecast Results

Applying the COMPASS™ Total Demand Model with the data inputs discussed in Chapter 4 (demographics, socioeconomics and transportation databases), generated the Total Demand Forecast presented in the following sections of this chapter, including the Hyperloop Ridership and Revenue results.

5.2.1 Total Demand

Using the Total Demand model, forecast of traffic was prepared for the Chicago to Pittsburgh via Cleveland Corridor. Exhibit 5-6 shows the Corridor total intercity Travel Demand Forecasts for 2020, 2030 and 2050. It can be seen that the travel demand will increase from 40.3 million in 2020, to 43.6 million in 2030, and increases to 50 million in 2050. The average annual corridor travel market growth rate is 0.72 percent per year, giving a 25% increase in total demand, which is in line with the socioeconomic growth within the travel market for the corridor.

Exhibit 5-6: Chicago to Pittsburgh via Cleveland Corridor Total Travel Demand Forecast (millions)

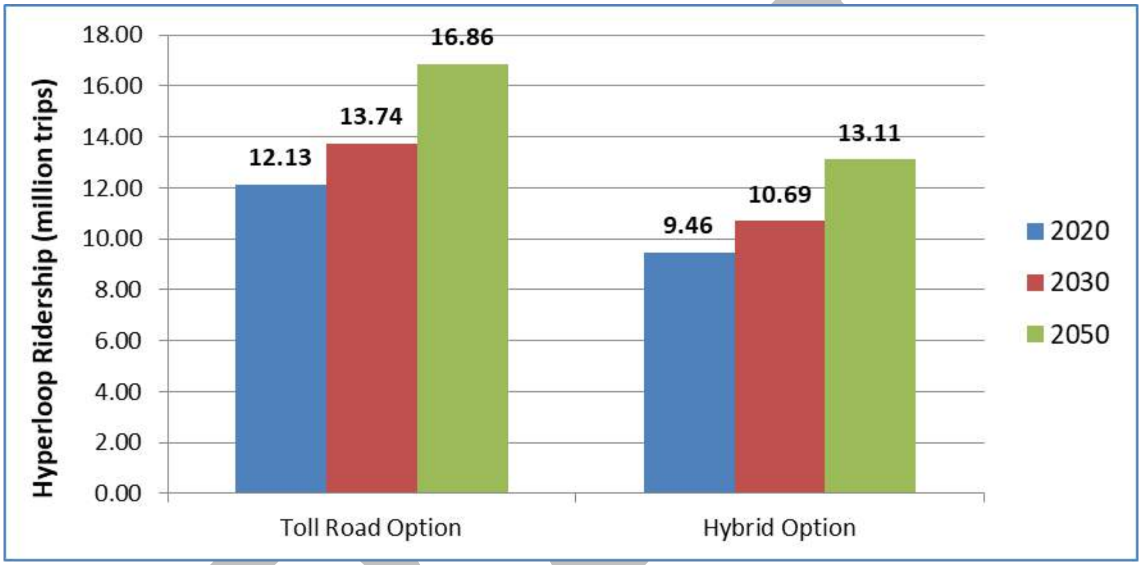


5.2.2 Ridership Forecasts

The Hyperloop ridership for each scenario and year is shown in Exhibits 5-7.

- The Toll Road Option is estimated to have 12.13 million trips in 2020, 13.74 million trips in 2030, and 16.86 million trips in 2050.
- The Hybrid Option is estimated to have 9.46 million trips in 2020, 10.69 million trips in 2030, and 13.11 million trips in 2050.

Exhibit 5-7: Hyperloop Chicago to Pittsburgh via Cleveland Ridership Forecast (annual millions of trips)

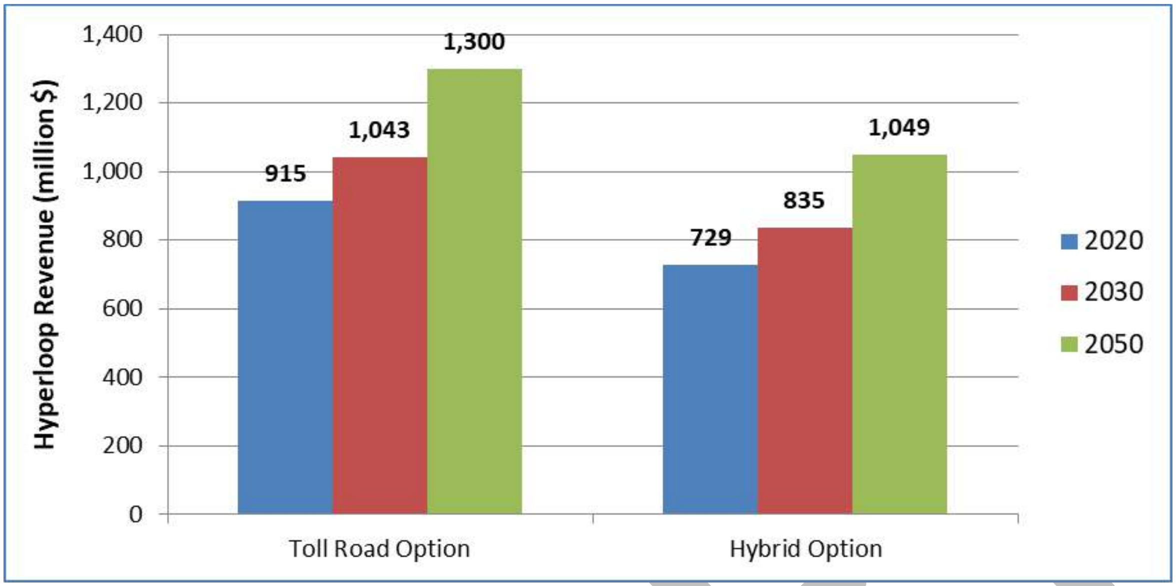


`5.2.3 Revenue Forecasts

The Hyperloop revenue forecast is shown in Exhibits 5-8.

- The Toll Road Option is estimated to have $915 million revenue in 2020, $1.043 million revenue in 2030, and $1,300 million revenue in 2050.
- The Hybrid Option is estimated to have $729 million revenue in 2020, $835 million revenue in 2030, and $1,049 million revenue in 2050.

Exhibit 5-8: Hyperloop Chicago to Pittsburgh via Cleveland Revenue Forecast (annual millions $)



5.2.4 Station Volumes

Exhibit 5-9 shows the station volumes. The strongest station volumes are projected to be at Chicago, Cleveland, and Pittsburgh. Chicago will have 6.81 million passenger volumes for the Toll Road Option and 6.13 million passenger volumes for the Hybrid Option in 2030. Cleveland will have 5.14 million and 4.48 million passengers for the Toll Road and Hybrid Options in 2030. Pittsburgh will have 6.25 million passengers for the Toll Road Option and 5.26 million for the Hybrid Option in 2030.

Exhibit 5-9: 2030 Station Volumes (millions of passengers)

	Toll Road Option	Hybrid Option
Chicago, IL	6.81	6.13
South Bend, IN	3.11	-
Toledo, OH	2.80	2.65
Hopkins Airport, OH	2.11	1.70
Cleveland, OH	5.14	4.48
Youngstown, OH	1.25	1.17
Pittsburgh, PA	6.25	5.26

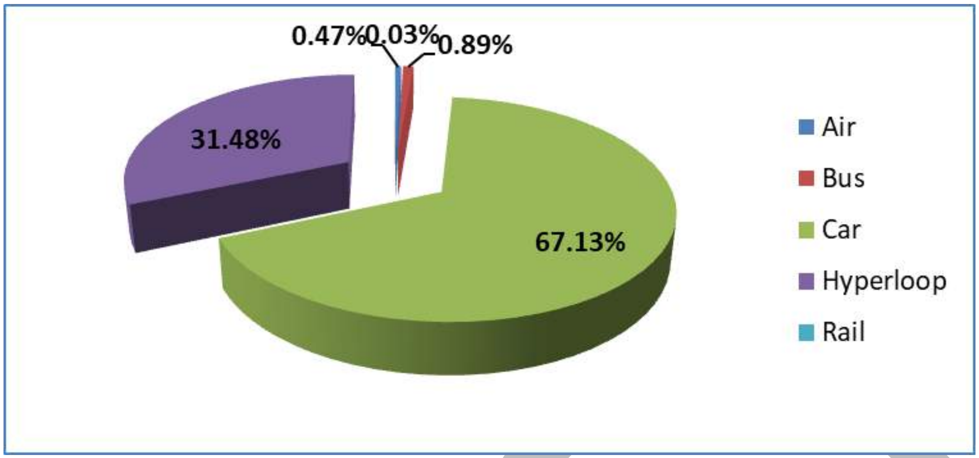
5.3 Market Shares

5.3.1 Travel Market Modal Split

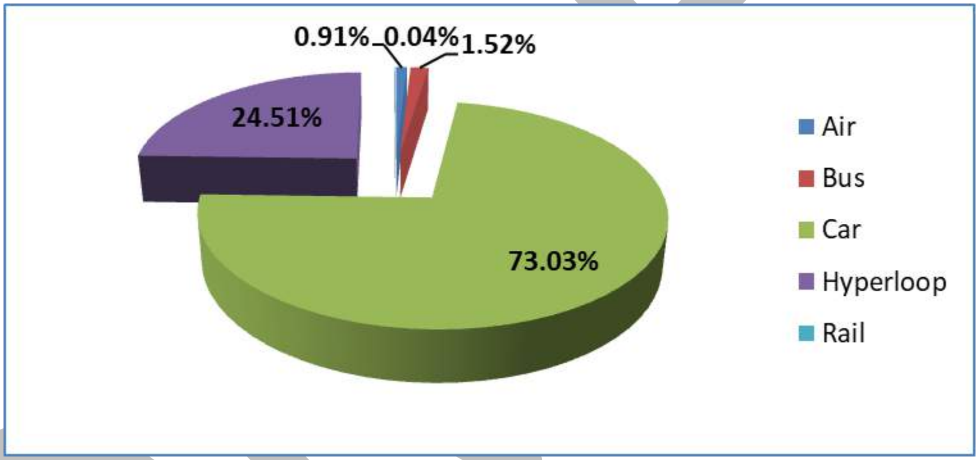
Exhibit 5-10 shows the corridor travel market shares in 2030. Hyperloop travel market share is 31.48% for Toll Road Option and 24.51% for Hybrid. Auto trips still dominate the travel market while its market share drops from over 90% to 67% ~ 73% due to the new Hyperloop service.

Exhibit 5-10: 2030 Chicago to Pittsburgh via Cleveland Corridor Travel Market Share

Toll Road Option



Hybrid Option

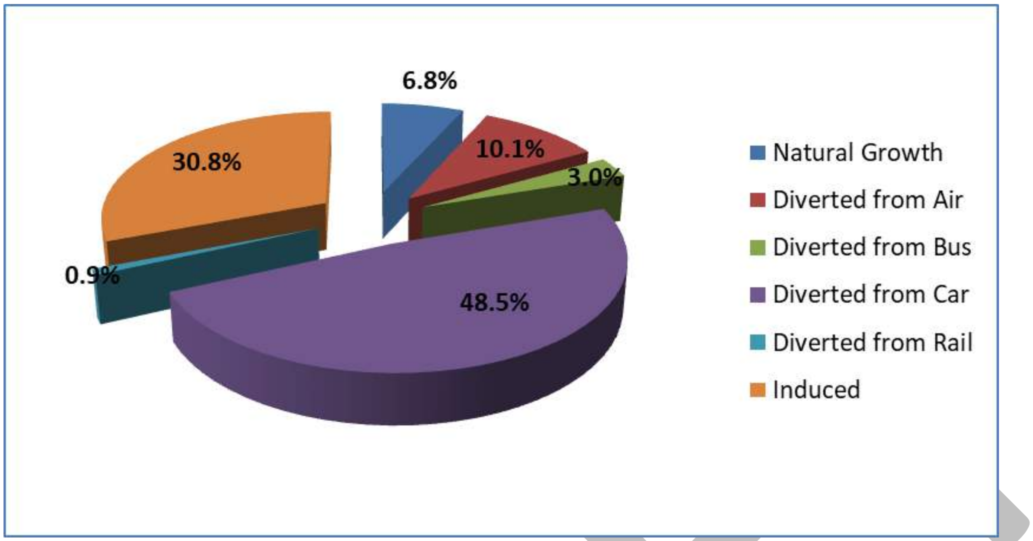


5.3.2 Source of Trips

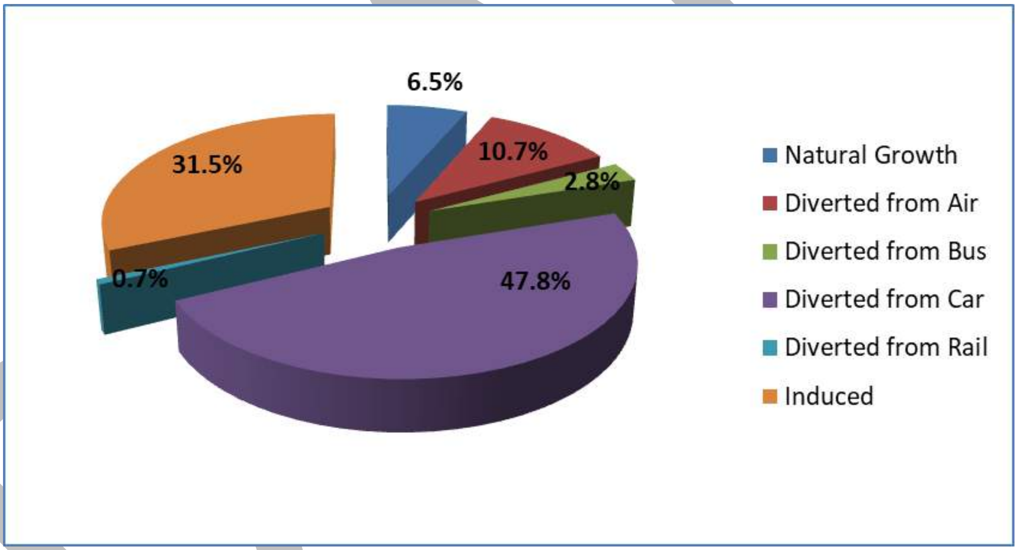
Exhibits 5-11 illustrate the sources of the Hyperloop trips in 2030. Trips diverted from other modes are the most important source of Hyperloop trips, which is estimated to be more than 50 percent of the overall Hyperloop travel market in 2030. Induced travel demand in the corridor as a result of the new hyperloop service is projected to be approximately 30 percent of the Hyperloop travel market then as well. As for the diverted trips from other modes, most trips are expected to be from personal auto travel. It should be noted however that driving still dominates the future travel market because it is the most popular travel choice in the corridor, and many trips are short and do not lend themselves to Hyperloop use.

Exhibit 5-11: 2030 Chicago to Pittsburgh via Cleveland Hyperloop Trip Sources Forecast

Toll Road Option



Hybrid Option

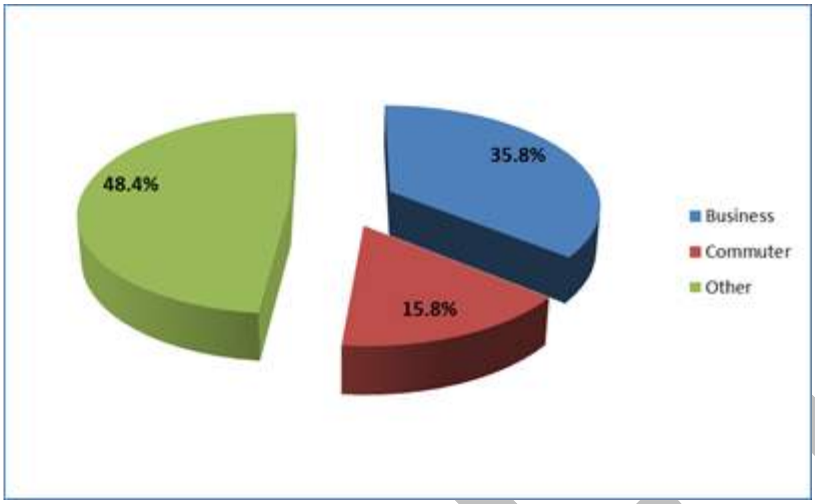


5.3.3 Hyperloop Trip Purpose Split

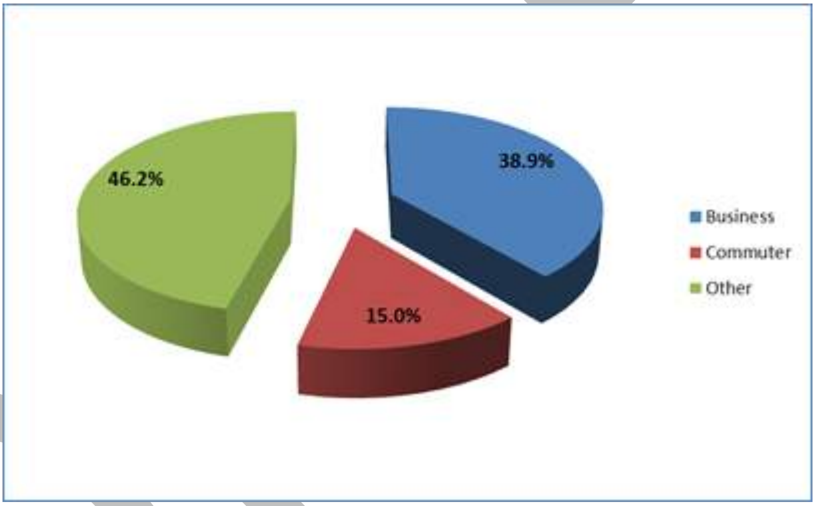
Exhibits 5-12 illustrate the purpose split of the Hyperloop trips in 2030. It can be seen that Business trips account for 35.8% of all trips in the Toll Road Option and 38.9% in Hybrid Option. For Hyperloop Commuter trips, the purpose split is 15.8% and 15% for Toll Road and Hybrid Options. The relatively modest share of commuter trips are due to the significant distance between HyperloopTT stations, since most existing commuter trips do not travel that far. Other Hyperloop trips have 46.2% and 48.4% for the two Hyperloop Options respectively.

Exhibit 5-12: 2030 Chicago to Pittsburgh via Cleveland Hyperloop Trip Purpose Split

Toll Road Option



Hybrid Option

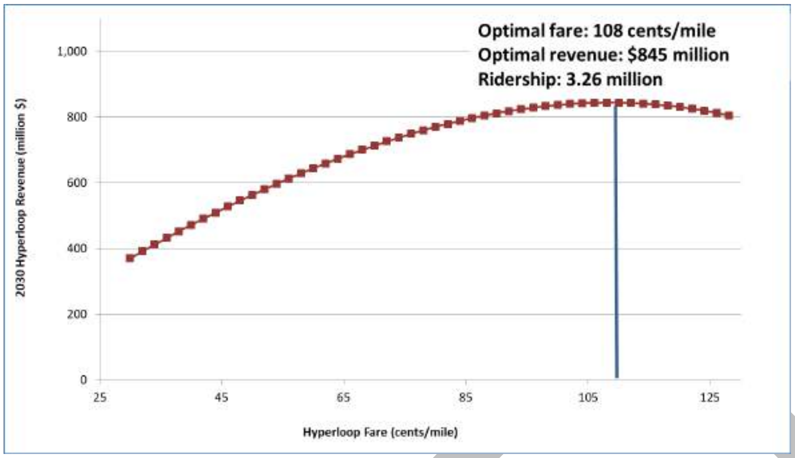


5.4 Yield Curve Analysis

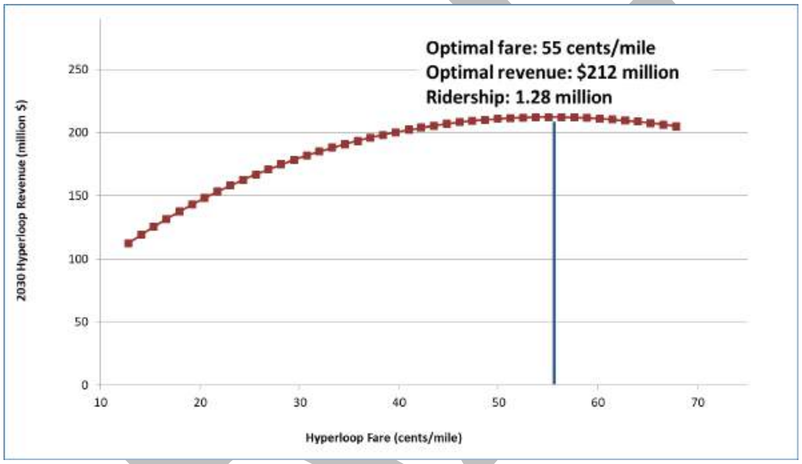
Exhibit 5-13 shows the yield curves of Hyperloop service in terms of Business, Commuter, and Other travel purposes. It can be seen that Business travel is the least sensitive to fare rate in the Hyperloop travel market, the revenue can be maximized by a fare rate of $1.08 per mile. Commuter and Other travelers are more sensitive to Hyperloop fare rates compared to Business travelers because they have lower values of time. For commuters, revenue can be maximized at fare rate of 55 cents per mile and for Other travelers, optimal revenue is achieved by charging 38 cents per mile. The average trip length for Hyperloop ridership is 240 miles for business, 240 miles for commuters and 300 miles for social travel.

Exhibit 5-13: 2030 Chicago to Pittsburgh via Cleveland Hyperloop Yield Curves

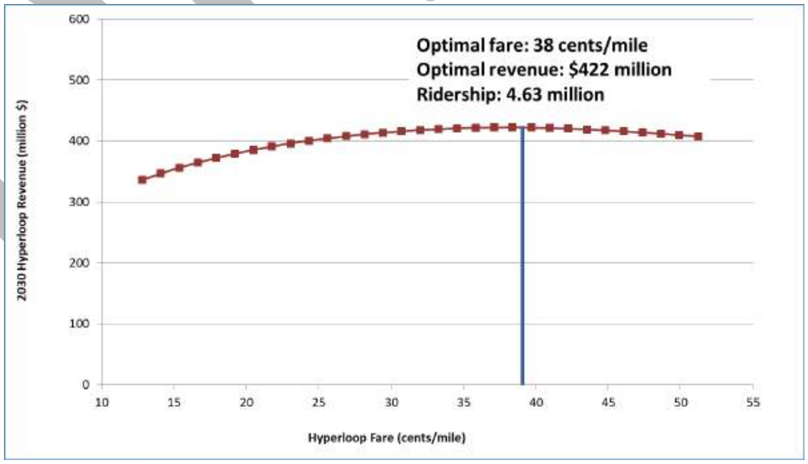
Business



Commuter



Other



Given the flatness of the revenue curves, the fares used in the current analysis are Social 25 cents per mile, Commuter 25 cents per mile, and Business 40 cents per mile: far lower than the optimal revenue maximizing fare. These fares are also well below both competitive air and Amtrak fares. In practice, fares will be heavily discounted for Commuter and Social travelers by the use of special tickets for Senior Citizens, Students, Families, and Off-Peak travelers, but may be raised for Business travelers who may be offered extra facilities. Overall fares will be lower than Amtrak or Air travel.

Chapter 6

Hyperloop Freight Market

Summary

This chapter focuses on the development of the express freight volume and revenue estimates that were used in the Great Lakes Hyperloop study.

6.1 Possible Freight Target Markets

Hyperloop promises to develop a freight service which is faster than truck and cheaper than air, which would undoubtedly position it as a premium freight service. It is possible that Hyperloop could also be cheaper than truck and faster than air, in which case Hyperloop would likely become a dominant mode for intercity freight transport, rather than just a niche provider of transportation services.

Either way, once Hyperloop becomes a reality, existing logistics patterns will adjust to take advantage of the capabilities of this new mode of transportation. Nonetheless, the more Hyperloop can fit into existing models for freight distribution, the easier it will be for Hyperloop to quickly gain market share. Minimizing changes that shippers, carriers and consignees must make would make it easy for them to add Hyperloop into their supply chains. There are at least four possible target markets that a Hyperloop could pursue:

Full Container or Truckload Service – one approach to the market would handle full sized trucks or shipping containers and move them point to point, similarly to how rail intermodal services work today as in Exhibit 6-1; but much faster and without the need for batching containers to build trains, since each container would move individually and on-demand. Such a system could handle 40’ ocean containers from ports; but Hyperloop could also participate in domestic markets if it had the ability to handle the larger 53’ containers that now predominate in domestic shipping lanes. For shorter trips it may even be attractive to use a roll-on-roll-off model that ferries the drivers and their tractors as in Exhibit 6-2. This would avoid the problems of needing large parking lots to store containers awaiting pickup at the destination.

The idea of shipping full truck loads or containers of freight by Hyperloop, including ocean containers, has attracted a lot of attention in the popular press. Certainly, it is technically feasible to do so, since magnetic levitation system designs have been developed specifically for this application, as in Exhibit 6-3.

Exhibit 6-1: Railroad and Truck Intermodal Yard for Full Container Service

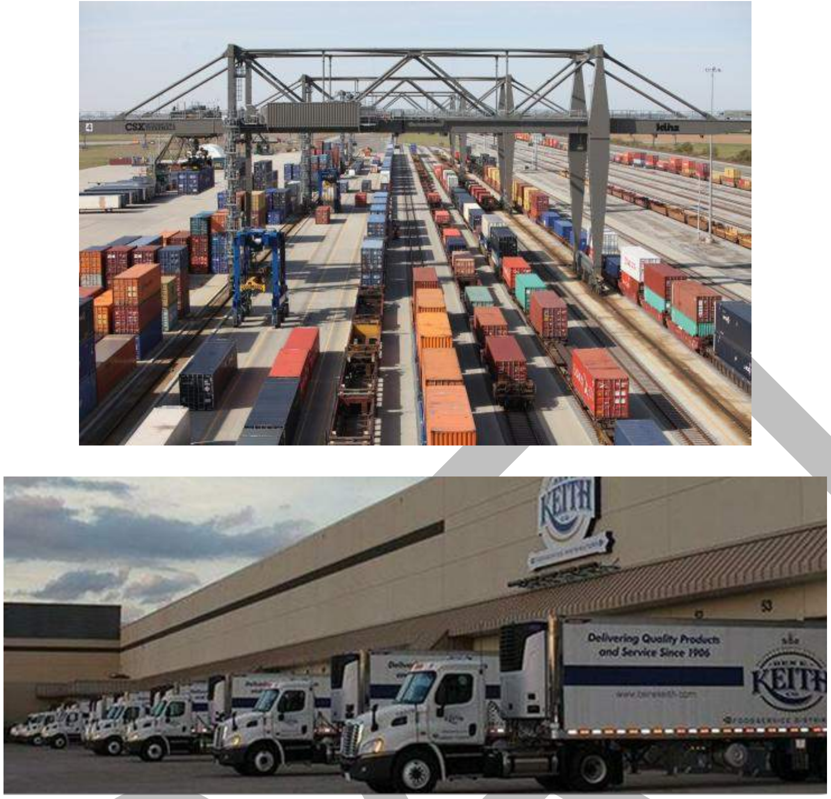


Exhibit 6-2: Semi-Truck Ferry Service in the EuroTunnel[4]

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[4] Photo source: https://www.eurotunnelfreight.com/uk/home/ on June 18, 2019

Exhibit 6-3: Inductrak III[5] for Magnetic Levitation of Containers

However, adding a capability for full container shipping would require a tube of a much larger internal diameter than the 4-meter tube that has been assumed for this study. Therefore, full sized ocean or domestic containers are simply too large[6] to fit inside the tube and therefore cannot be handled. It is likely that enlarging the tube to the size needed for handling full containers would entail an increase in the cost of both civil infrastructure and guideway[7]. HyperloopTT has been developing technology solutions for container shipping as part of its joint venture with HHLA[8], the operator of the Hamburg port. However, the costs and benefits of increasing the tube size to develop a container-compatible system have not been assessed by the current study.

However, by trans-loading freight from full sized containers into smaller “air cargo” type containers, Hyperloop could still capture some container freight, even with a smaller diameter tube. Many shipping containers (usually 30-50 percent of sea containers) are already trans-loaded or repacked at manufacturing and distribution sites near ports. This transload provides a ready opportunity for some of the freight to be repackaged for Hyperloop. The use of air cargo containers would certainly make sense for high value commodities, where Hyperloop’s much higher speed would justify the small additional cost.

Next Day Air Cargo Container Service – If Hyperloop connects airports, Hyperloop can compete with air cargo service by using air cargo containers as shown in Exhibit 6-4 and would run similarly to an airline. Hyperloop would be both time and cost competitive with air service and offer a more flexible service. This service would be primarily focused on overnight or next-day delivery. Air cargo containers are much smaller and lighter than ocean shipping containers and easily fit in the Hyperloop capsule. They are usually handled on a roller bed floor system[9] that can be powered for automated handling. While Hyperloop may compete with some air services, it would also connect with long haul air cargo services and would likely even exchange containers at the airports with connecting airlines.

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[5] *Inductrack III for superefficient levitation and movement of shipping containers*, retrieved from https://www.nextbigfuture.com/2013/05/inductrack-iii-for-superefficient.html on June 12, 2019

[6] A 53-ft domestic shipping container is considered a High Cube container. High Cube shipping containers are 9-ft 6-in tall on the exterior. They are 1-ft taller than standard height containers. They are also 8-ft 6-in wide, making them 6-in wider than standard ISO Ocean containers. See: http://containertech.com/container-sales/53ft-high-cube-container-domestic/ and http://containertech.com/container-sales/40ft-high-cube-container-standard-iso/ ; also see: http://containertech.com/container-sales/53ft-high-cube-container-domestic/, https://www.reddogologisticsinc.com/blog/different-shipping-container-sizes-and-what-theyre-used-for/, and https://www.up.com/customers/premium/emp/empcont/index.htm

[7] Using a larger tube would likely have a large impact on tunneling costs. Elevated guideway sections would have to be strengthened to take heavier loads. As well, the maglev guideway would have to be electrically strengthened using more powerful coils, both for levitation and also for propulsion of heavier container loads. Electric supply would have to be increased and the greater internal volume of the larger tubes would require more vacuum pumps.

[8] See https://www.bloomberg.com/news/articles/2018-12-05/hyperlooptt-signs-deal-to-build-a-328-foot-test-track-in-germany

[9] See for example:

- *"Airbus A330 /A340 Single LD3 Container Loading and Unloading Operation"* https://youtu.be/t2Eeap54OAQ
- *"Airport Crews loading/unloading at Kuala Lumpur (KLIA) International Airport (part 1)"* https://youtu.be/n_6Jd_aYCio
- *“Container Dolly In Operation At the Airport"* https://youtu.be/VRMlKaTpM04
- *"A320 A321 Cargo Loading Operations*" https://youtu.be/xwTXA2IGQfs

Exhibit 6-4: Air Cargo Container Service

LTL Ground Freight Market – A Hyperloop service using air cargo containers would be attractive not only to air freight, but if costs are low enough would likely attract a substantial share of palletized Less-Than-Truckload (LTL) ground freight as well. This is because LTL freight has to go through break bulk terminals just like air freight does, so using Hyperloop to replace truck for the line haul between terminals would not add significantly to the existing LTL cost structure. This is especially true if LTL break bulk terminals are located close to the Hyperloop freight depot.

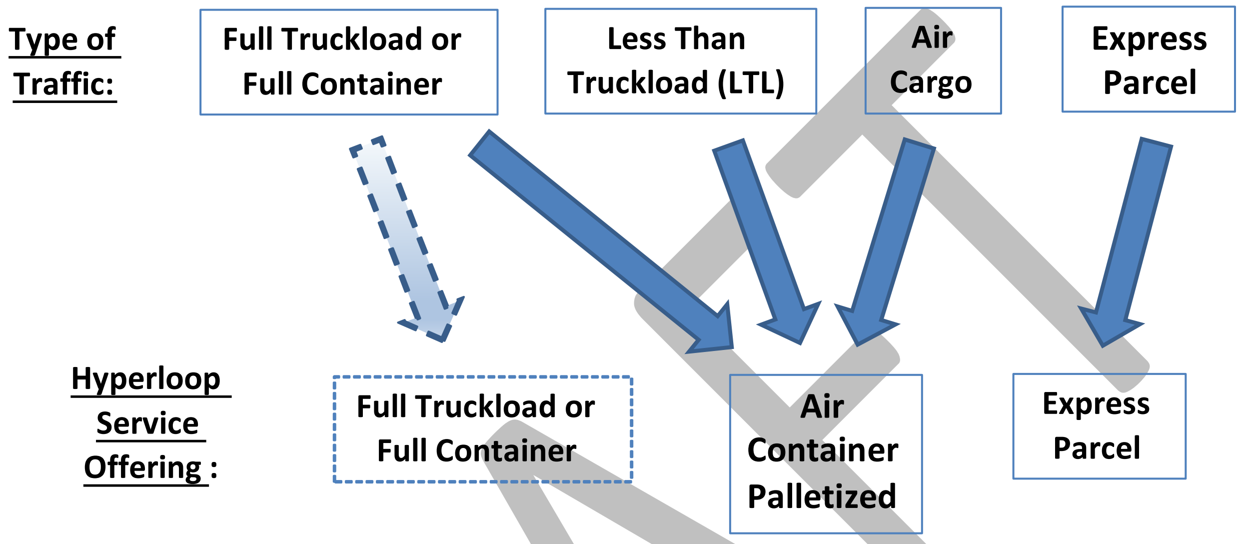
Same-day Express Parcel Service - would not likely use shipping containers at all, but rather would handle high value shipments individually or in mail bags, as the U.S. Postal Service does. This service would be primarily focused on same-day delivery. Express parcels could be shipped in passenger capsules as an adjunct to checked baggage service. Many airlines already move high priority freight and packages in the bellies of passenger planes along with luggage. Exhibit 6-5 shows an example of this type of cargo being loaded from a platform onto a Eurostar high-speed train. Express parcel freight will be very lightweight and relatively low volume from a tonnage perspective but will have a very high revenue yield and will generally requires custom handling to meet very tight delivery deadlines. This is why these packages can even be handled in the passenger capsules, since by so doing; these shipments can receive the highest possible level of expedited service. Pickup and delivery is likely to be provided by courier services (or drones in the near future) for the fastest possible delivery to customers.

Exhibit 6-5: Express Parcels being loaded onto a Eurostar Passenger Train

These service offerings are not mutually exclusive; Hyperloop can serve all four markets at the same time. With a large diameter tube, Hyperloop could move Full Truckloads or Containers. But even with only a small diameter tube, some Full Truckload or Container freight can still be accommodated by using the Air Container service. Air

Containers can accommodate a broad spectrum of freight as shown in Exhibit 6-6. Only the same-day express parcel freight would be separately handled due to its very high value and demanding service requirements, so that each parcel can be given individual attention to make sure it is expedited to its destination. The other categories of freight could all be accommodated by Air Container service.

Exhibit 6-6: Hyperloop Freight Market and Service Offerings



6.2 Hyperloop Freight Operations

This section will further detail the market, operating and business case for the proposed Air Container cargo system. This service would use commercial off-the-shelf air cargo containers which would be readily adaptable to the business models of both existing air cargo services, as well as less-than-truckload (LTL) ground freight trucking[10] services. Fundamental to the approach is the proposed use of air cargo containers by Hyperloop, also known as ULD's (Unit Load Devices) which are described by HiCargo[11] as follows:

> A unit load device (ULD, is a pallet or container used to load luggage, freight, and mail onto wide-body aircraft and specific narrow-body aircrafts. This allows a large quantity of cargo to be bundled into a single unit. Since this leads to fewer units to load, it saves ground crews time and effort, helps to prevent delayed flights and thus enhances the speed and efficiency of freight forwarding services. ULDs come in two forms: pallets and containers. ULD pallets are rugged sheets of aluminum with rims designed to lock onto cargo net lugs. ULD containers, also known as cans and pods, are closed containers made of aluminum or combination of aluminum (frame) and Lexan (walls). Depending on the nature of the goods to be transported, these may have built-in refrigeration units.

Air cargo containers come in a wide variety of shapes and sizes. These are suitable for handling many different kinds of freight and are also able to optimize the utilization of the fuselage or cargo hold space of different kinds of airplanes. Many existing configurations would fit well within the dimensions of HyperloopTT's capsules.

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[10] See: https://www.partnership.com/blog/post/ltl-vs-truckload-freight-what-s-the-difference

[11] HiCargo website, see http://www.hicargo.com/resource/container-information/air-freight-containers/

In terms of how air cargo and LTL trucking service work, it is likely that UPS, FedEx, Amazon, YRC and XPO would all be major users of the Hyperloop system, so we are using these carriers as representative of the operating methods used for most air cargo and less-than-truckload freight. Typically, these carriers use small trucks for local pickup and delivery, and they bring the freight into a "sorting center" which will put each package and freight pallet onto a larger truck (or aircraft) that is heading in the right direction. As a result, packages and LTL freight does not move directly from shipper to consignee, but rather goes through a sequence of sorting centers where it is transferred from one vehicle to another. Sometimes packages and palletized freight have to pass through two or three sort centers before reaching their destination. As a result, less-than-truckload (LTL) or air-cargo networks have a hub-and-spoke topology focusing on the locations of the sorting centers.

Exhibit 6-10 shows the locations of major airports, and urban terminals for LTL freight along the Chicago- Cleveland-Pittsburgh corridor. It can be seen that the major LTL centers cluster at airports and on the interstate highways and toll roads.

Exhibit 6-10: LTL Terminals Along Corridor

Functionally, each Hyperloop freight terminal needs to provide an empty container storage area as well as a packing/unloading area, so both palletized as well as containerized freight can be accommodated. A loading dock is needed for allowing trucks to deliver containers and palletized freight into the facility. If the terminal is within an airport, airport tugs and trailers may also transfer cargo directly to and from aircraft. For air cargo freight as planned, the terminal must be specially equipped. Roller floors commonly employed by air carriers would be used to speed up the container loading/unloading process. With roller floors, much of the container handling can even be automated.

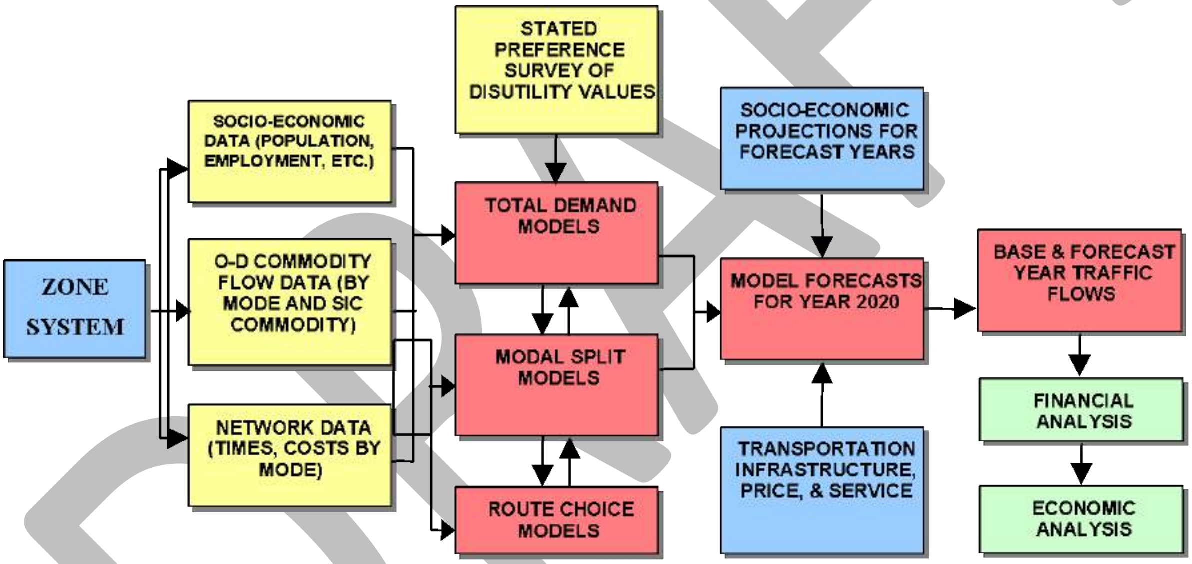
Some customers may choose to pack their own containers at off-site facilities, while other shippers will only send palletized freight to the Hyperloop terminal – this must be loaded into a container heading to the right destination, before the freight can be forwarded. Either way, this freight operation using air cargo containers could not be done in the passenger terminal; a separate freight terminal or at least separate area within the passenger terminal is needed for keeping freight and passengers out of each other's way.

While the proposed freight terminals with a 4-meter tube would only focus on handling air cargo containers, the more typical rail intermodal model for handling full truckload freight allows trucks to be loaded at the origin and move directly to destination without any intermediate loading or unloading. Most full truckload shippers will not want to pay the added cost associated with putting their freight through sorting centers and this freight would likely remain on the highway or move by rail. However, shipping in smaller lot sizes or pre-packaging the freight in air cargo containers may still prove attractive if the value of the freight is high enough. Most LTL freight and air cargo already moves in smaller lot sizes, because it has a higher average value per pound. From the carrier's perspective, LTL has also a higher freight revenue yield than does full truckload freight enabling the LTL trucking carriers to sustain profitability, whereas the full truckload carriers are often hard pressed to survive in the highly competitive trucking market. With a 4-meter tube, Hyperloop would be focusing on higher value smaller lot size shipments. using a consolidation process with sort centers and so would be focused on the most profitable segment of the freight shipping market. Air cargo containers are well suited to the requirements for handling air cargo and LTL freight and would be used for making the freight handling process more efficient.

6.3 Freight Market Analysis

Freight forecasts were developed using the GOODS™ model. The GOODS™ model system is a flexible multimodal freight forecasting tool that provides an assessment of decision makers' choices for various alternative modes of transport for different socioeconomic and network scenarios. Exhibit 6-11 shows the model structure.

Exhibit 6-11: GOODS™ Demand Model



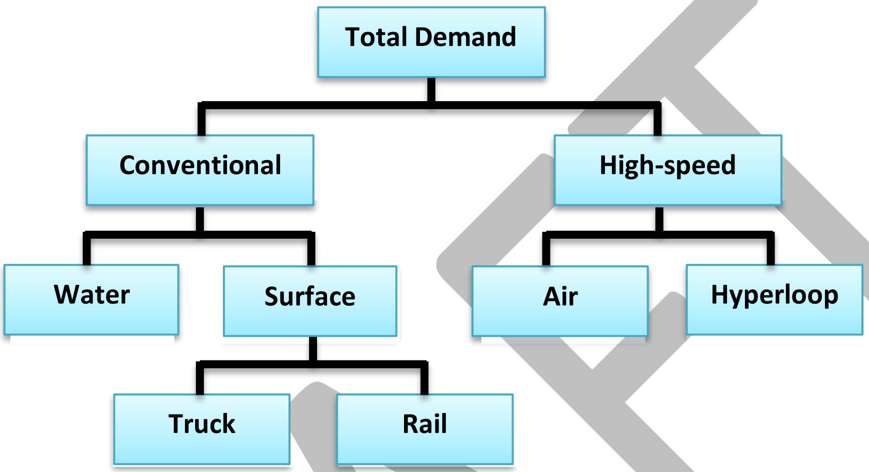
The GOODS™ model is a disaggregate analysis that involves –

- Total Demand
- Induced Demand
- Modal or Route Choice

Freight Forecasting Process - The Total Demand model is calibrated by commodity (e.g., food, raw materials, semi-finished goods, finished goods, etc.) depending on the type of traffic being considered. The model has been used extensively for both parcel traffic, and container traffic, each of which might be handled by a Hyperloop technology. For each commodity, the model is calibrated against the generalized cost of travel (time, cost, reliability etc.).

For the Great Lakes Hyperloop corridors there may be a series of existing modal options (e.g., truck, rail, water, air) which would compete for traffic. The decision choices as faced by the shipper are modeled on a hierarchical basis, as shown in Exhibit 6-12. If Hyperloop is developed it could become a fifth major option, so this mode is modeled separately from the others in the decision choice hierarchy. This modal choice structure is replicated for commodity, separately reflecting the generalized cost of transportation for each commodity, so that when the options are compared by mode pair in the hierarchy structure, each commodity model may behave differently.

Exhibit 6-12: Example Hierarchy for Inland Distribution for Truck, Rail, Water, Air and Hyperloop



Since the model is zone based, market shares and volumes of movement are forecast for each corridor by mode and commodity. This gives the ability to forecast for terminals and stations, and to show overall volumes and revenue for a corridor and given segments between stations and terminals.

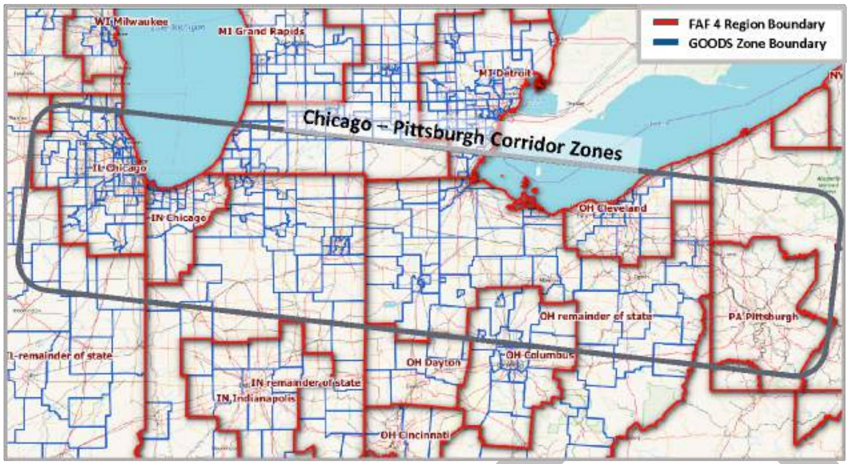
6.3.1 The GOODS™ Model Database

The GOODS™ model was developed using four key inputs as shown in Exhibit 6-18. These are a zone base set of –

- Socioeconomic Data
- O-D Commodity Flow Data
- Network Data
- Shipper Values of Time for Different Commodities

Zone System: The zone system is shown in Exhibit 6-13 showing the overlay between the very large zones used in the FAF-4 freight database as compared to the disaggregate zones that were used in the GOODS™ model. The same zone system was used in both the passenger and freight models. This provides the ability to model zonal access and egress times and costs on a reasonable basis.

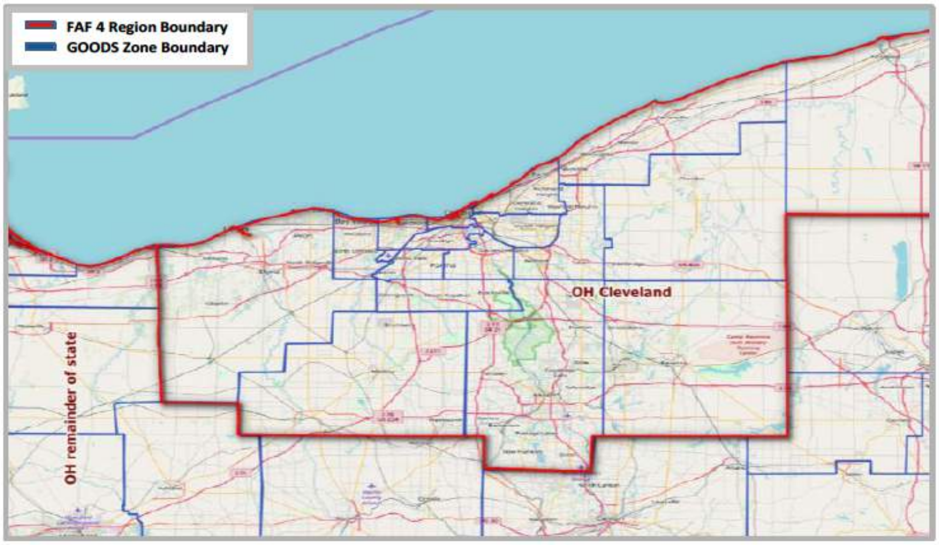
Exhibit 6-13: Pittsburgh-Cleveland-Chicago Express Commodity Distribution by Tonnage



However, as previously pointed out in the modeling of the mode choice decision for line-haul transportation, only the locations of the LTL and air cargo sorting hubs matter, since local pickup and delivery trucks bring all the freight to these locations before the freight is dispatched on its line haul. As a result even though the model provides the potential for having many zones, only the subset of zones that actually contain an LTL sorting hub need to be considered in the modal choice model. This greatly simplifies the structure of the freight model since there are generally only a few zones that need to be connected with access links to the expected locations of the Hyperloop freight terminals.

Socioeconomic Data: In addition to showing the disaggregate GOODS™ zones, the zoomed map on Exhibit 6-14 shows the USDOT Freight Analysis Framework (FAF4) zones provided control totals for the regional movement of freight between major metropolitan areas. This provided a "Benchmark" for the freight flows generated by the GOODS™ model from US Census Data, Piers Import/Export Data, US Public Waybill Data, and the commodity flow data of the US Bureau of Transportation Statistics (BTS) Freight Analysis Framework.

Exhibit 6-14: "Zoom" of Cleveland Area Freight vs Passenger Zone System



The larger, brown-outlined zones in Exhibits 6-14 show FAF-4 Zones, as very large zones covering an entire city or SMSA, except that zones that span across State boundary lanes (such as "IN-Chicago") were split by FAF-4 at the state lines. The freight data from BTS has been summarized at the level of these large zones. Smaller, blue-outlined zones show the Transportation zones that are used in the GOODS™ model for demand forecasting. Most GOODS™ zones uniquely map into one FAF-4 zone – however, it is clear that the GOODS™ zone system is much more detailed and refined than are the FAF-4 zones.

However, one reason why FAF-4 has kept its very large zones is to protect the confidentiality of its freight survey respondents. FAF-4 commodities are classified at the 2-digit level of the Standard Classification of Transported Goods (SCTG)[12] whereas some earlier data products, including the 1993 Commodity Flow Survey[13] used a completely different classification scheme that was based on the Standard Transportation Commodity Code (STCC.) Knowing the specific SCTG commodity (like Pharmaceuticals, which was not reported as a separate category in earlier data sets) one may easily be able to identify specific companies if the FAF-4 zones were too small. Therefore, there is a trade-off in freight data between the size of the zone and the level of detail in commodity reporting. FAF-4 has opted to report the commodities in a fairly fine resolution, but this requires the use of large zones.

As a result, the advantage of using the GOODS™ model is its ability to provide a more accurate modeling of access and egress times to and from Hyperloop freight terminals. This improves modal and route split analysis, especially for fixed link systems that needs the best assessment of "door to door" times. As such, Rail and Airport mode terminals are typically located at the locations closest to their markets. The key is to avoid lengthy truck drayage activity (i.e., using a truck for pickup and delivery) to final origins and destinations.

Truck drayage rates per mile are a multiple (2 to 4 times) more than typical truck rates for intercity line-haul moves. This behooves shippers to cluster as close to terminals as possible for minimizing the truck drayage charges, and in fact is what the railroads are doing when they promote their so-called "Logistics Park" concepts[14], or truckers to locate at good access points along interstates and toll roads. Accurately modeling of access times and costs is critical to predicting intermodal market shares for freight shipping, since if a customer is located too far away from the terminal (because of the high drayage charges at both ends of the move) it may actually be cheaper to truck the container directly to destination.

However, Air Cargo and LTL freight work differently from full truckload freight:

- LTL freight sends delivery trucks out of a local area terminal to pick up pallets and packages.
- Regardless of final destination, all the pallets and packages are going to be brought back to a central sorting hub (or "break bulk") location to be sorted and loaded onto another truck or airplane that is heading in the correct direction.
- The delivery process works in reverse.

As a result, for Air Cargo and LTL freight, **it is not the actual location of the shipper or consignee that matters, rather the location of the "break bulk" or sorting hub. Many times, these facilities are near airports or junctions of interstate highways, since these locations naturally attract logistics activity.**

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[12] Oak Ridge National Laboratory, *FREIGHT ANALYSIS FRAMEWORK VERSION 4 User's Guide for Release 4.0*, October 31, 2015, at https://faf.ornl.gov/fafweb/data/FAF4%20User%20Guide.pdf

[13] See: https://www.bts.gov/archive/publications/commodity_flow_survey/1993/united_states/index

[14] See: https://www.bnsf.com/ship-with-bnsf/rail-development/logistics-parks.html

For example, the UPS facility for Cleveland is located at 15775 Industrial Parkway, less than 10 minutes from Hopkins Airport. Some other freight carriers have chosen to hub at Akron-Canton airport rather than at Hopkins, but most of them are clustered near one of these two regional airports. This consolidation simplifies the modeling exercise for LTL freight, since it actually allows the modal choice decision to be modeled by connecting only a small number of zones. For modeling the dynamics of rail intermodal or full-container shipments, every single zone would be needed for accurately modeling drayage access times and costs, which are strongly influenced by mileage.

Because of this, a simplified network can be used for Hyperloop which is in fact very similar to the Air network as shown in Exhibit 6-18. Each link in the line-haul network reflects the travel time of a capsule between stations. The decision choice then, is whether to use truck, air or Hyperloop to move a ton of freight between any two specific sort centers or stations. The sort centers are generally close to the Hyperloop terminals, which minimizes the time and cost for transferring cargo between the Hyperloop terminal and the sort center. These locations have been identified in Exhibit 6-10. The modeling of the centroid connectors beyond the sort hubs to outlying zones can actually be ignored since the freight movement only needs to be modeled as far as the sort centers, and local pickup and delivery links will always be the same, regardless of which line-haul mode is used to provide the connection between sort centers.

6.3.2 Origin Destination Data

The USDOT FHWA Freight Analysis Framework (FAF-4) database was used as a control total for assessing the freight market for the Cleveland, Chicago and Pittsburgh corridor. This database[15] was produced through a partnership between the Bureau of Transportation Statistics (BTS) and the Federal Highway Administration (FHWA), and it integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. Starting with data from the 2012 Commodity Flow Survey (CFS) and international trade data from the Census Bureau, FAF incorporates data from agriculture, extraction, utility, construction, service, and other sectors.

The FAF version 4 (FAF4) baseline edition provides aggregate metropolitan area to metropolitan area estimates for tonnage and value by regions of origin and destination, commodity type, and mode for 2012, the most recent CFS year. Data are available through the Data Extraction Tool, for download as a complete database, as well as summary files. Additionally, it provides forecasts through 2045; state-to-state flows for 1997, 2002, and 2007; truck flows assigned to the highway network for 2012 and 2045; and domestic ton-miles and distance bands. Exhibit 6-15 summarizes the historical 2012 and forecast 2040 total market of express freight moving within the corridor by all modes.

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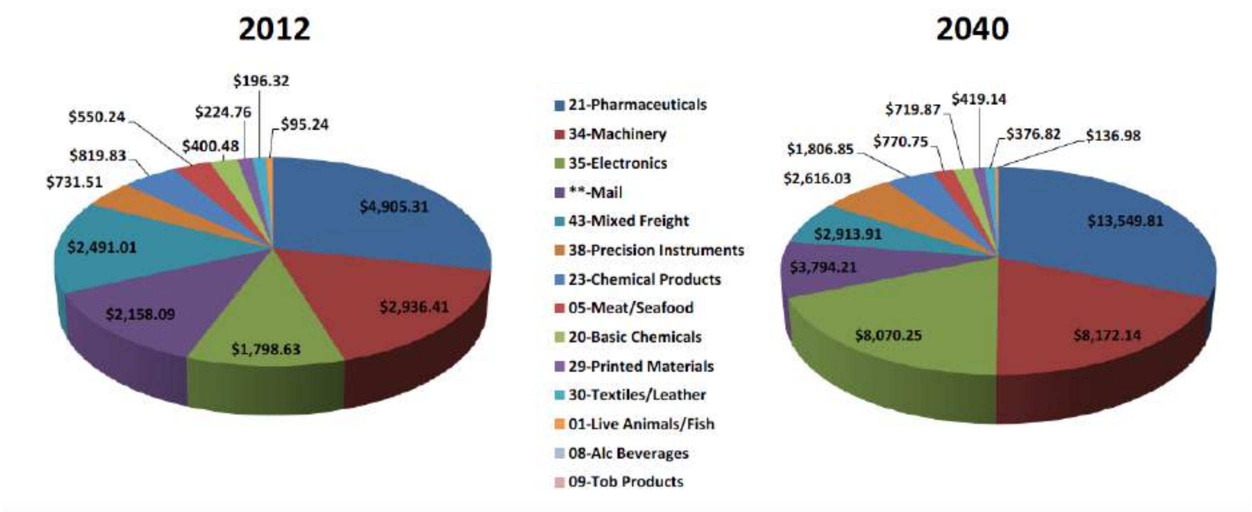
[15] *Freight Analysis Framework,* see: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/

Exhibit 6-15: Express Freight Total Market Forecast: Pittsburgh-Cleveland-Chicago

		2012			2040		
	Commodity	Value ($ mill)	Tons (mill)	Avg $/Pound	Value ($ mill)	Tons (mill)	Avg $/Pound
**	Mail	$2,158.09	0.04	**$26.73**	$3,794.21	0.07	**$27.00**
01	Live Animals/Fish	$95.24	0.05	**$0.93**	$136.98	0.07	**$0.97**
05	Meat/Seafood	$550.24	0.12	**$2.33**	$770.75	0.12	**$3.17**
20	Basic Chemicals	$400.48	0.22	**$0.91**	$719.87	0.38	**$0.95**
21	Pharmaceuticals	$4,905.31	0.02	**$143.54**	$13,549.81	0.03	**$222.66**
23	Chemical Products	$819.83	0.32	**$1.29**	$1,806.85	0.60	**$1.52**
30	Textiles/Leather	$196.32	0.01	**$8.61**	$376.82	0.02	**$10.22**
35	Electronics	$1,798.63	0.12	**$7.81**	$8,070.25	0.26	**$15.42**
38	Precision Instruments	$731.51	0.01	**$37.42**	$2,616.03	0.03	**$42.28**
08	Alc Beverages	$0.28	0.00	**$2.67**	$0.52	0.00	**$2.66**
09	Tob Products	$0.32	0.00	**$0.66**	$0.02	0.00	**$0.67**
29	Printed Materials	$224.76	0.07	**$1.72**	$419.14	0.14	**$1.52**
34	Machinery	$2,936.41	0.23	**$6.51**	$8,172.14	0.46	**$8.88**
43	Mixed Freight	$2,491.01	0.53	$2.36	$2,913.91	0.57	$2.55
	TOTAL	**$17,308.42**	**1.72**	**$5.03**	**$43,347.29**	**2.75**	**$7.89**
			Ratio 2012-2040		***250%***	***160%***	***157%***

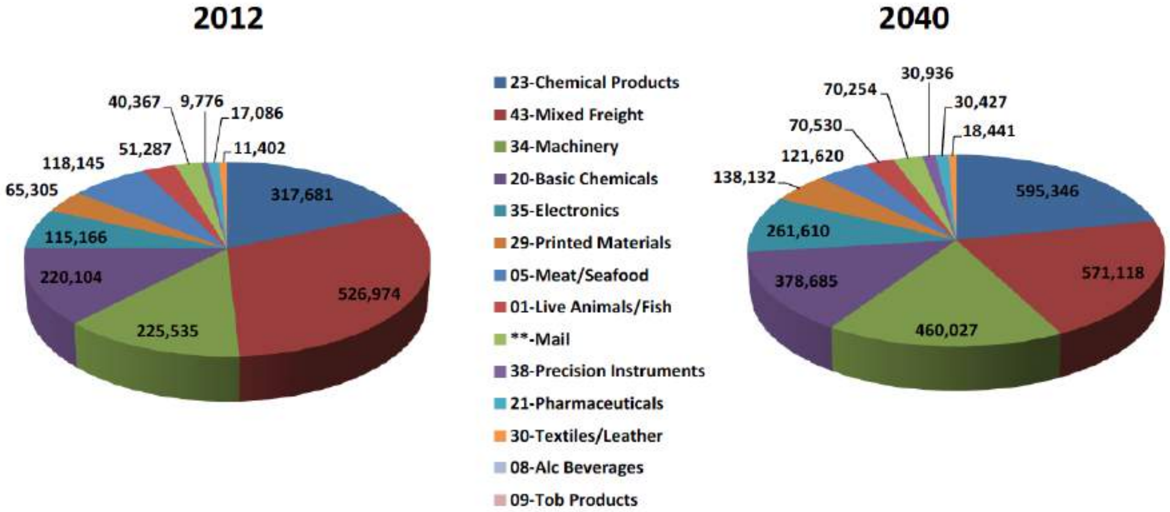
This freight with a forecasted average value in 2040 of $7.89 per pound is clearly very high value. It will have a correspondingly high Value of Time and require expedited handling such as Hyperloop could provide. Exhibits 6-16 and 6-17 show the corresponding 2012 and 2040 commodity breakdowns by value and tonnage, each pie chart is sorted from greatest to least 2040 value or tonnage.

Exhibit 6-16: Pittsburgh-Cleveland-Chicago Express Commodity Distribution by Value



This shows that by 2040 on a value basis, Pharmaceuticals, Machinery, Electronics and Mail will account for 77% of the total value of express goods shipped; whereas on a tonnage basis, Chemical Products, Mixed Freight, Machinery and Basic Chemicals will account for 73% of the tonnage. This traffic is currently moving by rail and truck within the corridor limits which are shown in Exhibit 6-13. As a result, the forecast could be considered conservative since it does not consider the possibility of freight originating or terminating outside the study area that could also use the system for a portion of the distance.

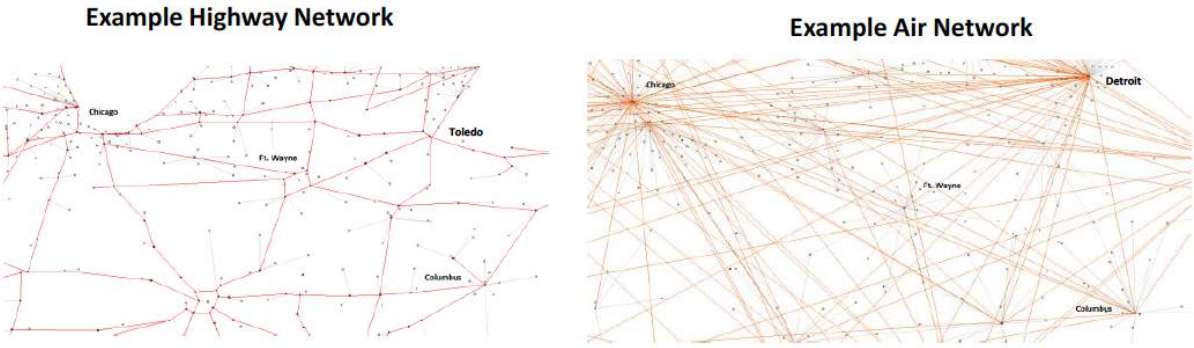
Exhibit 6-17: Pittsburgh-Cleveland-Chicago Express Commodity Distribution by Tonnage



6.3.3 Network Data

For each freight mode time and cost networks are developed showing the relative competitiveness of the different modes in moving freight. Exhibit 6-18 shows the highway and air networks that were developed for the corridor. For each network the "Generalized Cost" of traffic movement that combines both time and cost was calculated.

Exhibit 6-18: Competitive Network Representation in the GOODS^{TM} model



6.4 Hyperloop Freight Operating Costs

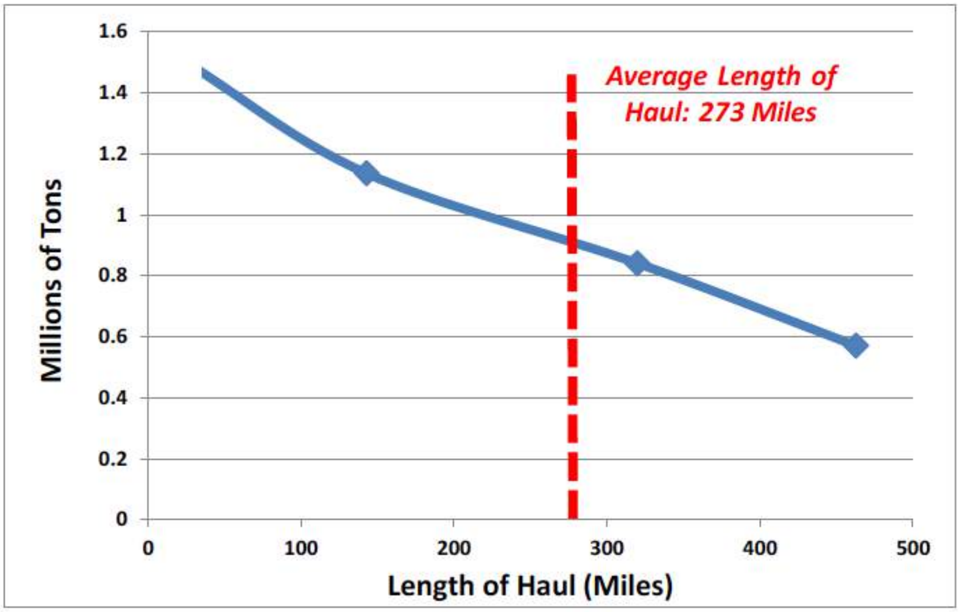
The selection of candidate commodities has to be consistent with the capabilities and strengths of any proposed mode. Hyperloop is going to be a very fast mode of transportation but also because it will be operating automated capsules inside of an evacuated tube, its energy efficiency is expected to be very high and its costs very low, and it will prove highly competitive with air and truck.

The operating cost and efficiency of moving freight by Hyperloop will ultimately prove to be a large determinant of the market share that Hyperloop is able to achieve. The reason for this is that depending on the time sensitivity and other handling characteristics of the freight, there is a maximum tariff level that shippers are going to be willing to pay before they would shift their freight back to other modes. As a result, Hyperloop's operating cost has to be less than this tariff level, or else the system would lose money on every ton it hauls.

An operating cost for express freight has been estimated by using the same Operating Cost framework for Hyperloop that will be detailed in Chapter 8; however, only a subset of those costs are directly attributable to freight. For example, the guideway system is already there – if the guideway has capacity for freight at certain time, then the operation of freight capsules is not likely to significantly change that cost. The capsules will consume some energy for propulsion and levitation, which is a legitimate cost of the freight operation and will be included here. However, the effect on guideway maintenance cost is extremely weak, and the costs for pulling and maintaining a vacuum in the tubes won't be affected at all by whether freight capsules operate.

As a result, it is appropriate to estimate the incremental costs of adding freight service as compared to the incremental revenues that might be available from freight. As long as the revenue minus cost remains positive, then freight can help contribute to the bottom line of the system. It is not necessary to get into any allocation or cost sharing methodologies for dividing fixed costs between passengers and freight, since these costs won't change. As a result, an incremental costing approach was used.

Exhibit 6-19: LTL Freight



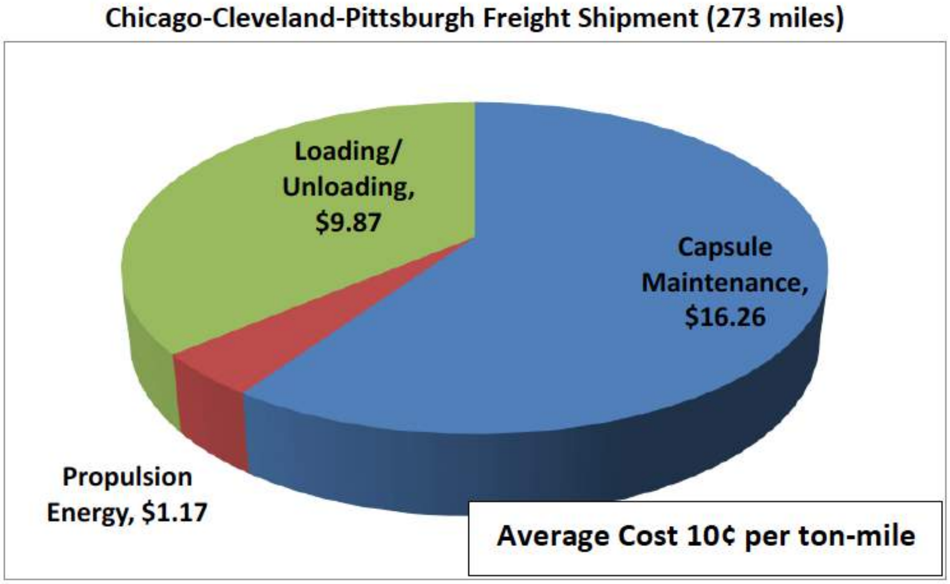
Note: Distribution is truncated because the total length of corridor is just 463 miles.

Exhibit 6-19 shows the average length of haul for LTL and Air Cargo freight in the Chicago-Cleveland-Pittsburgh corridor will be 273 miles; based on this, exhibit 6-20 shows the cost breakdown. Key findings are that:

- The marginal costs of freight movement are going to be dominated by loading/unloading (terminal) costs and capsule maintenance costs.
- There are no operating labor costs since the freight capsules will be automated and can operate unattended.
- It is considered that the freight operation will have no significant impact on marginal guideway, passenger related costs or system overheads.
- Energy costs will be very low, even though it has been assumed that the energy costs will rise from 4.2¢/capsule mile up to 6.0¢/capsule mile due to the heavier average load (14 net tons) of the cargo capsules. This reflects the extremely energy efficient nature of the proposed Inductrak guideway with 200:1 Lift to Drag ratios, the fact that the system would be operating in an evacuated tube, and assumed use of

regenerative braking resulting in a substantial recovery of most of the acceleration energy when the capsule reaches its destination.

Exhibit 6-20: Estimated Hyperloop Operating Cost Per Ton for Chicago-Cleveland-Pittsburgh Freight Shipment (273 miles)



For understanding how these projected Hyperloop costs compare to existing modes, a benchmark comparison was done. For example, the Trucker's Report[16] gives an historical average operating cost for a fully loaded semi-truck of $1.38 per mile, which according to ATRI has by now increased to $1.69 per mile[17]. Of course, this is not the full cost of trucking since it is only for a fully loaded truck, and does not necessarily account for bobtailing, empty repositioning and partial loads that would be encountered by a real-world trucking operation.

As according to Ship North America transportation[18], a typical 53' dry van trailer has a Tare Weight of 15,000 pounds and a Gross Vehicle Weight of 44,000 pounds. This means it can carry a maximum payload of 29,000 pounds or 14.5 tons. Dividing this by $1.69 gives an average operating cost of 11.6¢ per ton mile. Of course, the average LTL truck will cube-out before it weighs out:

Getting the best possible freight density per trailer, the goal of ODFL and every other LTL company, also comes into play. The goal is to fill that cube before hitting the maximum weight[19].

Not fully loading the truck would increase the LTL trucker's average cost per ton-mile even more. Torian**[20]** summarized the costs of the four existing modes (with Hyperloop added for comparison) as in Exhibit 6-21:

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[16] Trucker's Report, *The Real Cost of Trucking – Per Mile Operating Cost of a Commercial Truck*, retrieved from https://www.thetruckersreport.com/infographics/cost-of-trucking/

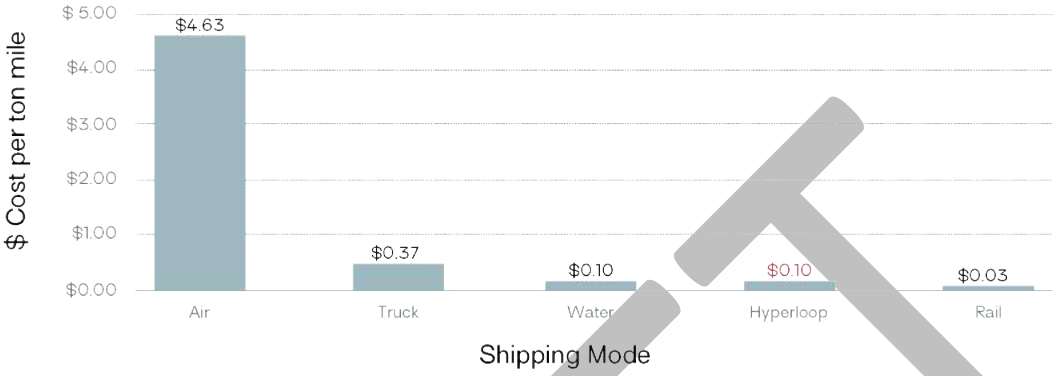
[17] ATRI, *Cost of Operating a Truck Up 6% to $1.69 Per Mile, ATRI Report Says*, https://www.ttnews.com/articles/cost-operating-truck-6-169-mile-atri-report-says

[18] See: https://www.shipnorthamerica.com/htmfiles/equipment.html

[19] Journal of Commerce, US surface shippers 'shifting' truck modes more, see: https://www.joc.com/trucking-logistics/ltl-shipping/old-dominion-freight-line/us-shippers-'shifting'-modes-more-ltl-data-suggest_20180731.html

[20] See: http://richardtorian.blogspot.com/2012/01/cost-per-ton-mile-for-four-shipping.html based on 2002 data

Exhibit 6-21: Cost per Ton Mile for Shipping Modes



On this basis, it can be seen that rail is the most cost-effective shipping mode followed by water (river barge); but Torian's comparison reflects the economics of inland water transportation, which is very peaked and unidirectional. If Hyperloop's cost is only 10¢ per ton mile compared to trucking's 37¢, or air freight's $4.63 per ton mile then Hyperloop's operating costs will be not only air competitive, but also truck competitive. This means that the Hyperloop mode will be very competitive not only for air freight, but also for LTL truck freight.

6.5 Hyperloop Freight Revenue Yields

In terms of the revenues available from freight, the Bureau of Transportation Statistics (BTS) annually updates a table of average revenue yields by mode[21]; for 2017 the BTS gave the following average revenue yields per ton mile of freight:

- Air: $1.27
- Rail: $0.04
- Truck: Unavailable, but it would be $0.22 if it increased at the same rate as rail has since 2007

BTS's revenue yields for trucking include those for full-truckload service; however, LTL revenue yields are much higher on a ton-mile basis than those for full truckload shipping, so BTS's data clearly underrepresents LTL trucking rates. A relevant LTL trucking rate would be at least 2-3 times this level so the revenue of LTL trucking would generally be in the range of $0.44-0.66 per ton mile, as compared to a trucking cost of $0.37. This affords the LTL trucker a substantial profit; nonetheless, if Hyperloop can deliver the same or better transportation service at a cost of only $0.10 per ton mile its economics are going to be even better than that of trucking, let alone air freight.

However, for full container or truckload movement, it appears that rail shipping will remain a lot cheaper than Hyperloop. As a result, railroads with their lower operating costs, would likely be able to undercut Hyperloop on price in major lanes like Philadelphia to Chicago (as they already undercut truckers) for the movement of bulk freight that is not particularly time sensitive. Nonetheless, rail competition is not much of a factor on short lanes like

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[21] See: https://www.bts.gov/content/average-freight-revenue-ton-mile

Cleveland to Chicago, since railroads typically do not compete for loads under 1,000 miles and even then, would compete for such loads only in high volume lanes between major cities.

This suggests that:

- Hyperloop's business model benefit from passengers who, in fact, pay the lion's share of the cost both for building and maintaining the infrastructure. This will give Hyperloop freight a significant advantage and will enable it to effectively compete for truck traffic in shorter haul lanes than are feasible for rail.
- The railroads need enough traffic between each origin and destination to build full sized trains, but since Hyperloop handles freight in individual capsules rather than in large trains, this will give it an advantage in lanes which don't have enough density to justify running whole trains, yet Hyperloop can still offer direct point-to-point service.

As a result, the projected revenue yields for Hyperloop service as developed for the Financial analysis are:

- 35¢ per ton mile for LTL freight. At 14 tons per fully loaded capsule LTL freight revenue would be worth $4.90 per capsule mile.
- 50¢ per ton mile for air cargo. At 14 tons per fully loaded capsule Air Cargo freight revenue would be worth $7.00 per capsule mile.

At these proposed rate levels, Hyperloop service would be very cost competitive as against the cost of LTL or Air Cargo shipping and be able to attract significant volumes of both ground LTL and air freight to the system. At this level of pricing:

- LTL freight would contribute 25¢ per ton mile to the bottom line (as 35¢ revenue - 10¢ cost).
- Air Cargo would contribute 40¢ per ton mile to the bottom line (as 50¢ revenue - 10¢ cost).

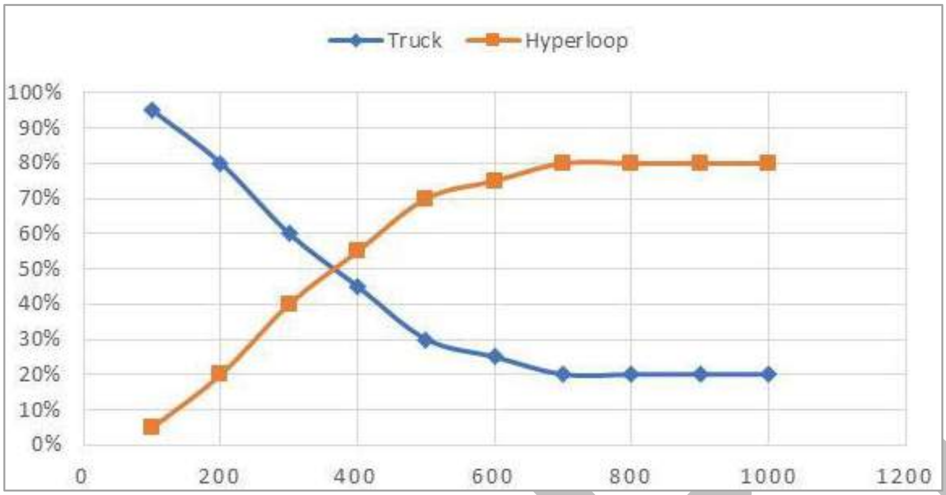
6.6 Forecasts for Hyperloop Air Cargo Container Service

Hyperloop clearly provides a much faster transportation system than truck and will even offer highly competitive times to air service. The key issue is how important is terminal to terminal time for specific commodities. Raw materials, for example, often move by railcar today since time is not critical. These commodities are highly price sensitive rather than time sensitive and these commodity groups can be safety ignored for modeling of Hyperloop.

Hyperloop can capture some Intermediate goods and food traffic but will likely attain a market share of only 30-40% at the 600-mile distance range. From Chicago to Cleveland and Pittsburgh, a Hyperloop will not likely capture much of this freight since the distance is too short. This is consistent with the low average value per ton of these commodities and the fact that even most perishable food, if refrigerated is not all that time sensitive. For example, even though bananas are perishable they are sent refrigerated by ship from Central America into the US, which takes 5 to 8 days.

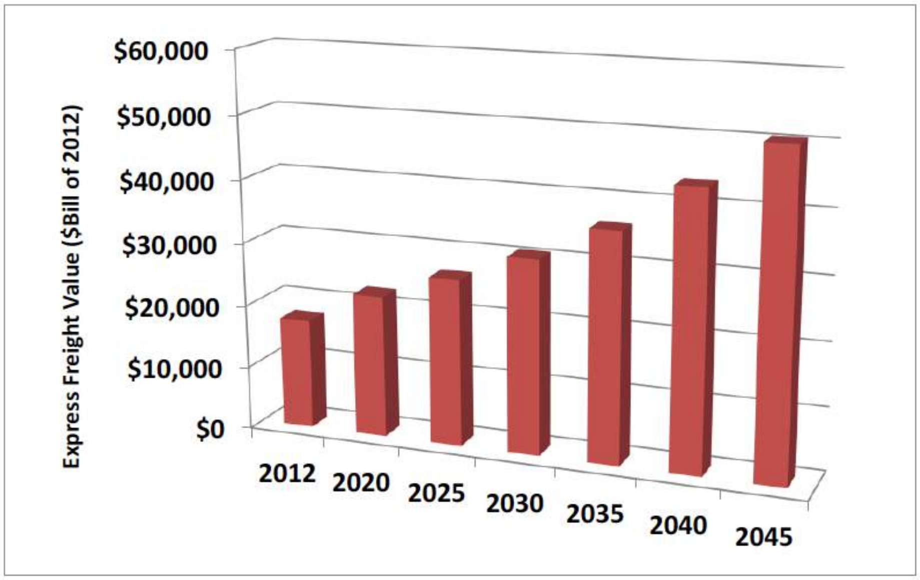
Finished goods are the most time sensitive and so Hyperloop will likely attain about 45% market share vs. truck at a 350-mile distance. However, it is important to keep in mind that this estimate includes certain finished goods commodities such as Furniture and Transportation Equipment, that depress the market share estimate. This shows that not all finished goods are time sensitive, particularly goods like automobile parts and furniture that are moving to replenish dealer inventories rather than to fulfill actual customer orders. However, the same commodities could become very time sensitive if they are moving by E-Commerce direct to customers. E-Commerce orders are perhaps the most time sensitive with major suppliers like Amazon demanding faster and faster delivery times. Other commodities such as pharmaceuticals are much more time sensitive than the average finished goods due to their extremely high value per pound. Exhibit 6-22 summarizes the Forecast results for finished goods.

Exhibit 6-22: Truck vs. Hyperloop Market Shares for Finished Goods



Using the GOODS™ model and the FAF4 control totals, total market forecasts were made for the high value commodities shown in Exhibit 6-15 for the Chicago-Cleveland-Pittsburgh market. As shown in Exhibit 6-23 the analysis shows a Compound Rate of Growth of 3.2% per year (by Cargo Value) over the 33-year period from 2012 to 2045, resulting in nearly tripling the freight market over the forecasted time frame. This is a very conservative rate of growth for some segments of the business, e.g. E-Commerce which is now growing at up to 15% per year but is still higher than the annual growth rates that are used for forecasting passenger traffic growth.

Exhibit 6-23: Forecasted Cargo Value by Year, 2012-2045



The FAF forecasts are very conservative for an energy-efficient mode like Hyperloop, since oil prices are forecasted to rise in the future and congestion on the highways continues to worsen. Both of these factors are going to drive traffic growth to Hyperloop at a rate greater than the 3.2% per year that was forecasted by FAF, which is basically just a trend-line projection. 2022 is the first year of operation of the proposed system in the Financial and Economic

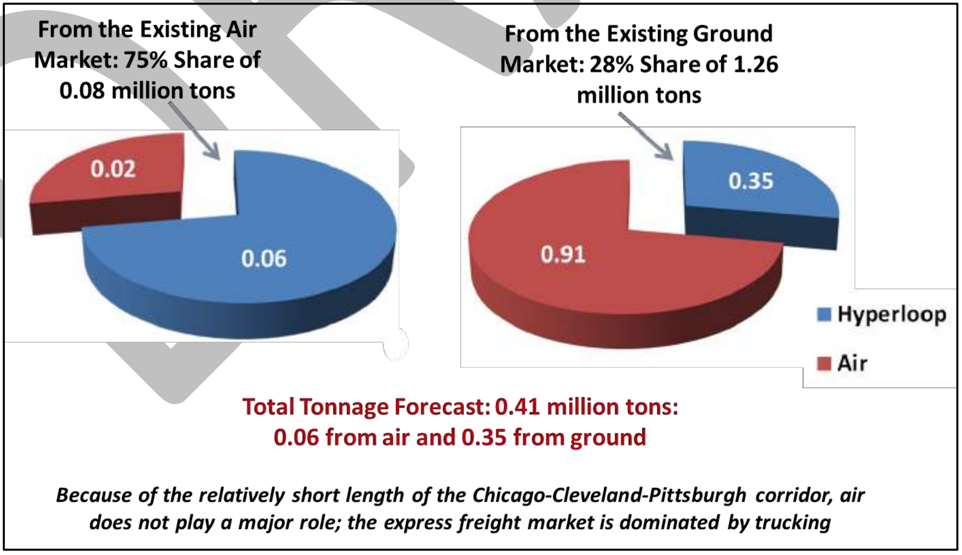
Analysis, so the freight forecasts have been developed for that year. As a result, a 4% annual growth rate in LTL traffic and a 5% annual growth rate in Air Cargo has been assumed after 2022.

The calibrated GOODS™ hierarchical modal split model for Finished Goods was used for estimating the modal split for Express freight in this study. As a result, predicted modal shares for a 300-400 mile Hyperloop trip were slightly higher than what had been predicted for a slower maglev system. This reflects the faster speed of Hyperloop coupled with high VOTs of the freight traffic mix, and short access times for LTL and Air Cargo freight to the Hyperloop terminal.

Exhibit 6-24 shows forecasted Hyperloop tonnage for 2022 as well as how that traffic is currently moving:

- According to FAF-4 there are only 80,000 tons of air cargo moving annually within the corridor, most of that from Cleveland to Chicago. Hyperloop service will be both faster and much cheaper than the existing air service, so a 76% market share has been projected. Even so, this only produces 60,000 tons of cargo per year for Hyperloop in 2022 due to the relatively small amount of air freight moving in the corridor today.
- The LTL ground express market is much larger, consisting of 1.26 million tons of express cargo in 2022. Of this, Hyperloop is forecasted to capture a 28% share, which results in 350,000 tons of freight captured by the Hyperloop system in 2022, which is the first year of operations.
- The overall freight tonnage therefore is 410,000 per year which is 31% of the overall express freight that will be available in the Chicago-Cleveland-Pittsburgh corridor by 2022. It is clear that most of this volume would be attracted from ground LTL freight due to the relatively small share of Air Cargo moving within this corridor. If the corridor were longer than it is, then the Air Cargo share of freight might be expected to increase.
- This forecast grows by 4% for LTL traffic and a 5% for Air Cargo tonnage every year.
- The average length of haul within the corridor has been estimated as 327 miles for Air Cargo. Pittsburgh to Cleveland LTL tonnage reduces the average to 273 miles for LTL freight.

Exhibit 6-24: Forecasted Hyperloop Tonnage by Source of Traffic for 2022, Chicago to Pittsburgh via Cleveland



From the Existing Air Market: 75% Share of 0.08 million tons

From the Existing Ground Market: 28% Share of 1.26 million tons

Total Tonnage Forecast: 0.41 million tons: 0.06 from air and 0.35 from ground

Because of the relatively short length of the Chicago-Cleveland-Pittsburgh corridor, air does not play a major role; the express freight market is dominated by trucking

6.7 Forecasts for Hyperloop Same-Day Parcel Service

As previously described in Exhibit 6-6, same-day parcel service will be operated separately due to the extremely high service requirement of same-day parcel delivery. This section will summarize the market, operating and business case for a Hyperloop express parcel service. This would be modeled after Eurostar's Esprit and British Rail's former Red Star Parcel business. It is assumed that parcels may be shipped along with the baggage in the passenger capsules themselves, so the service would operate as an adjunct to passenger checked baggage service rather than as a dedicated freight service.

Package express service would be for light parcels and is designed for same-day package delivery. It would use couriers to pick up and deliver packages from rail stations. In the future, drones may substitute for couriers as the scope of the service expands. Alternatively, customers could bring their own packages to and from the stations if they want a lower cost, and do not want to employ a courier service. This type of operation was extensively studied and has been well documented as part of the Midwest Regional Rail System plan. By comparison, overnight or two-day delivery would be more typical for Air Cargo or LTL service (considered previously.)

It is noted that because of E-commerce and development of fulfillment centers, the express freight market has been growing rapidly in recent years, as fast as 15% per year and this explosive rate of growth is expected to continue through at least 2025. Demand doubles every 6-8 years. The express parcel segment is growing rapidly as customers have become emboldened to demand same-day E-commerce services, and retailers have innovated on developing many new ways for delivering it. Same day service, in particular, has a very high service requirement. As a result, it can afford to pay the higher rates associated with a premium service. This traffic is much more lucrative than heavy freight, and Hyperloop has the ability to compete for it.

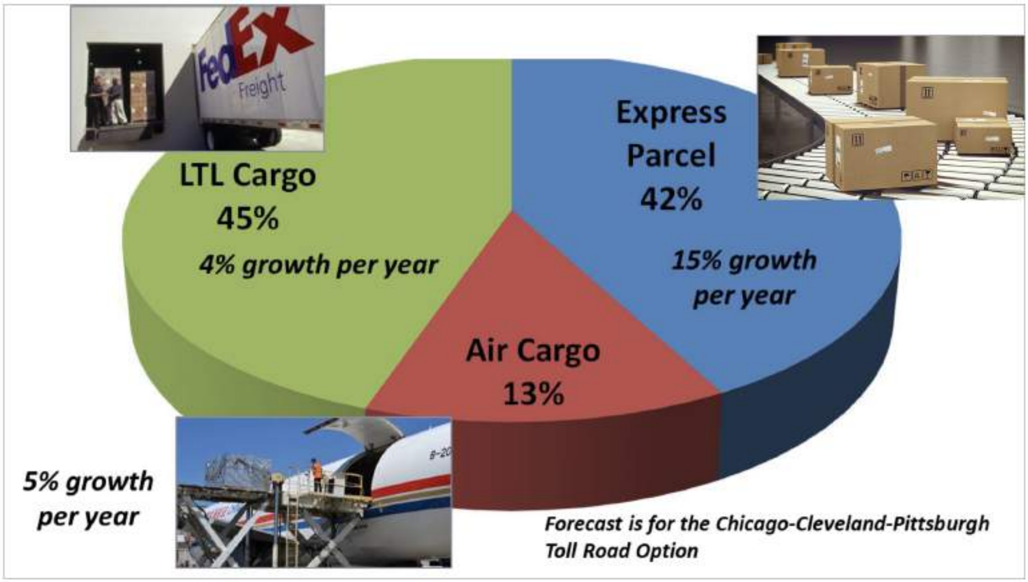
While the total revenue generation capability of express parcel traffic is substantial, it is estimated that 70% of those revenues would be consumed by pickup and delivery couriers; 15% would be absorbed as station operations cost so that only a residual 15% of total revenues would be left over as a contribution to Hyperloop operations. This express traffic does not add much to the system operating cost, so the 15% net residual can be directly transferred to the Hyperloop system's financial statement.

The demand for express parcel service has been growing rapidly since the early 2000's, so that by 2029 this service is been projected to add about 20% to the passenger revenues of the system. If the rate of growth of E-commerce continues unabated beyond 2029 as it is expected to do, the level of revenue contribution would above 20% with very little operating cost impact, since E-commerce has been growing much faster than the rate of passenger demand.

6.8 Overall Express Freight Forecast

A breakdown of the forecasted 2022 Freight Revenue for the Hyperloop system in Chicago-Cleveland-Pittsburgh corridor is shown in Exhibit 6-25. This date was chosen for this comparison because it reflects a market forecast that is similar to current market conditions and thus can be easier to visualize. The total freight revenue for 2022 is $224 million including LTL, Air Cargo and Express Parcel. By 2040 it grows to $838 million, primarily reflecting the very high rate of growth and very high revenues associated with development of the same-day Express Parcel business.

Exhibit 6-25: 2022 Freight Revenue Forecast



Chapter 7

Capital Costs

Summary

This chapter develops Capital Costs for various alignment options. It develops a discussion of capital costing issues along with a preliminary estimate of infrastructure capital costs. These estimated costs are consistent with the infrastructure assumed needed to provide point-to-point running times that were developed in Chapter 3 and have been used as the input to the evaluation process.

7.1 Key System Components

Hyperloop is a new transportation technology whose components are all available in the existing marketplace. Engineering work is ongoing to appropriately integrate and optimize these technologies, with passenger safety and comfort, transportation efficiency, and energy efficiency as primary design criteria. HyperloopTT engineering teams and industrial partners are analysing, simulating and designing to ensure technology readiness, and are working to validate systems and subsystems. The HyperloopTT system includes key technology components as described in Chapter 3. Capital costs for technology elements include categories for Capsule, Linear Infrastructure, and Stations, each of which are applied on a per-capsule, per-mile, or per-station basis.

The capsule costs include the capsule fuselage, capsule power, communications, and life support systems, passenger and cargo interiors, and capsule bogies that contain the levitation, motor, and wheel equipment that enables capsule movement. The linear infrastructure costs include the tubes, pylons, levitation system, propulsion system, control, communications, and traffic management, and power supply. Station costs include the spaces and equipment that enable efficient circulation of passengers, cargo, and capsules.

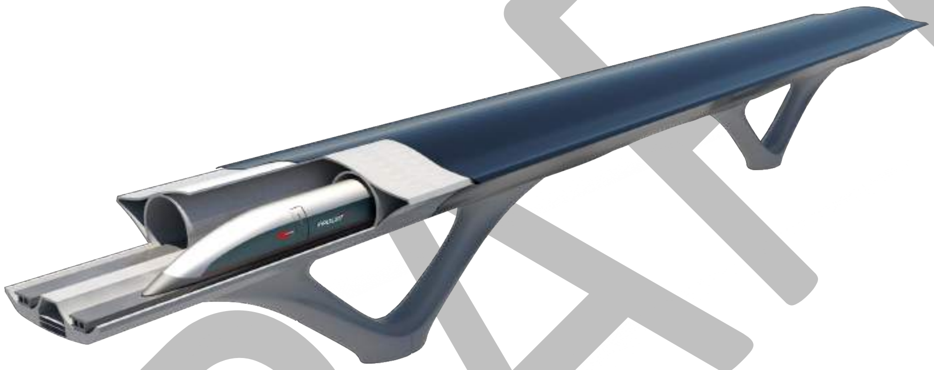
7.2 Civil Works

Civil Works for HyperloopTT will consist of site access and grading; site preparation for utility and foundations; stormwater management; installation of water supply and treatment, wastewater collection, treatment and disposal; and installation of building and pylon foundations, and on-site temporary and permanent roadways and parking facilities. These facilities will be designed to meet all local regulations and site conditions using typical engineering practices.

Right-of-Way and Easements - Where public highways are used or in deep tunnel it is assumed there is no land acquisition cost although there may be costs for both temporary and permanent easements.

At Grade and Elevated Sections - A Hyperloop capsule requires guideway support, and it needs to be enclosed in a tube even on level ground. An elevated tube will also provide structural strength for the span, as well as the vacuum enclosure. A concept for the elevated guideway is shown in Exhibit 7-2.The tube structure is continuous over multiple spans, but it can be curved and the guideway internally super elevated to meet geometric and lateral acceleration requirements.

Exhibit 7-2: Elevated Guideway Structure[22]



However, if the tube is in contact with the ground or buried, the tube does not need to provide structural support; rather, the tube only needs to enclose and protect the vacuum environment within.

Tunneled Sections - In areas of variable terrain, or to pass underneath built-up urban areas, tunnels are appropriate to reduce unreasonable grades, maintain a smooth profile with long vertical and horizontal curves, and avoid surface disruption and visual impacts. Bored tunnels can be used for this purpose. These tunnels need to have at least 30 feet of overburden before a Tunnel Boring Machine (TBM) can be used. Depths shallower than this would be constructed by using open trenching methods. While highway and railway tunnels tend to be of very large diameter (8 to 14 meters), the HyperloopTT system operates with a much smaller 4-meter diameter tunnel. This significantly reduces capital costs. On intervals of about 5 miles, an underground chamber and cross link between tubes will be constructed to enable emergency evacuation of capsules and access to the tubes for emergency and maintenance personnel.

Underwater tunnels will be more expensive than tunnels under land, primarily because the emergency evacuation and fire accessibility requirements for long underwater tunnels are much more stringent. This could likely increase their cost by a factor of 3 or more as compared to land-based tunnels, unless the tunnels are constructed close to

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[22] Source for both photos: Presentation, OTEC Conference, October 3, 2018

shore where emergency accessibility is much easier to provide. Tunnels under lakes proposed for the Great Lakes Hyperloop project are planned to be close to shore to provide accessibility.

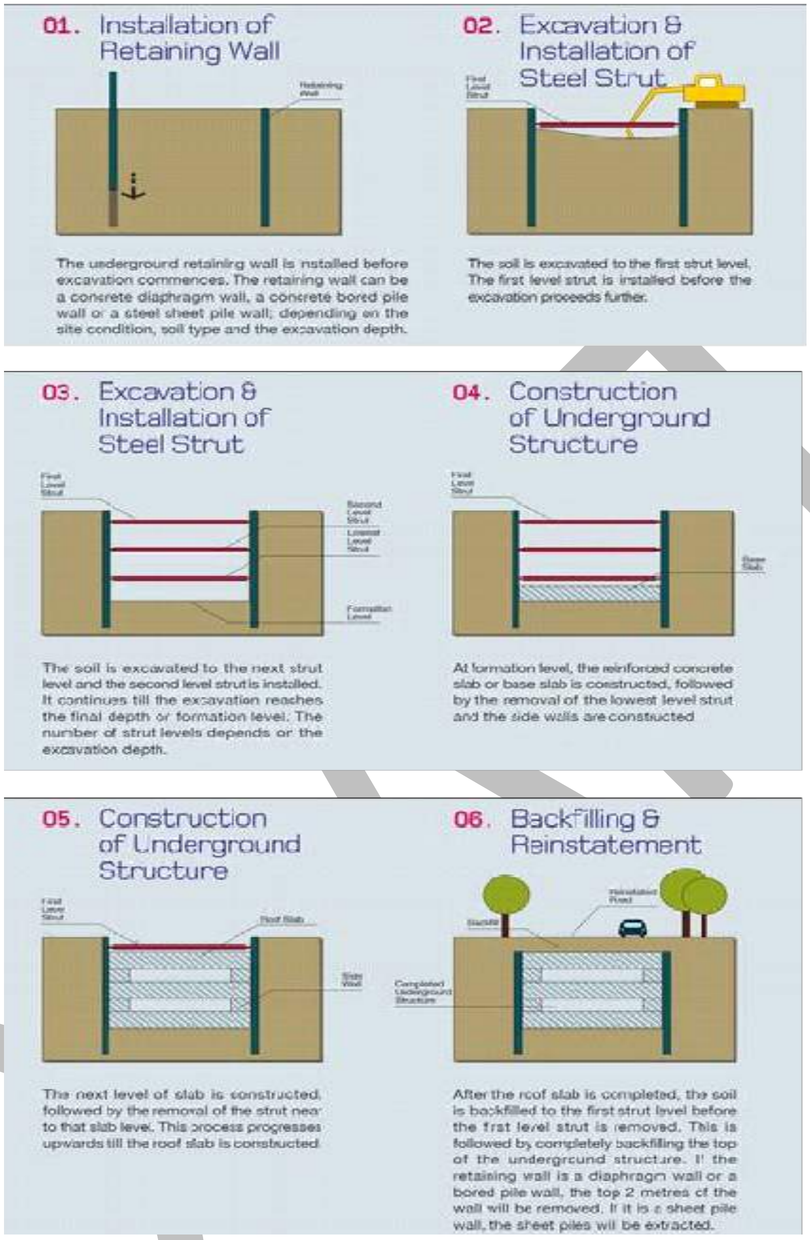
For shallow tunnels as shown in Exhibits 7-5, cut and cover tunnel can be used. The costing of cut-and-cover tunnels can be complicated, depending on the exact construction techniques that have to be employed.

- In urban areas as shown in Exhibit 7-5, construction typically requires installation of underground retaining walls to reinforce both sides of a vertical excavation and prevent cave-ins. After this, the area between the walls is excavated and cross-braces are installed to reinforce the retaining walls. After the tunnel is complete the tops of the tunnels can be backfilled, and the retaining walls removed. Utility relocation costs have to be separately estimated. If extensive utility relocation is needed, a deep bored tunnel is usually going to be more economical.

- In a rural area it may be possible to excavate a trench and slope the trench walls consistent with local building code requirements. HyperloopTT tubes can be completely covered to allow the resumption of farming operations or normal surface uses as soon as installation of the tubes has been completed.

- Finally, when constructing alongside an active rail line or highway within 25 feet of the centerline of rail tracks or highway lanes, an underground retaining wall may be needed to protect the rail or highway side of the excavation, but not the other. This cost for constructing a cut and cover tunnel close alongside active rail tracks has been estimated as part way between the cost of an urban vs. rural cut and cover tunnel.

Exhibit 7-5: Cut and Cover Tunnel



01. Installation of Retaining Wall

The underground retaining wall is installed before excavation commences. The retaining wall can be a concrete diaphragm wall, a concrete bored pile wall or a steel sheet pile wall; depending on the site condition, soil type and the excavation depth.

02. Excavation & Installation of Steel Strut

The soil is excavated to the first strut level. The first level strut is installed before the excavation proceeds further.

03. Excavation & Installation of Steel Strut

The soil is excavated to the next strut level and the second level strut is installed. It continues till the excavation reaches the final depth or formation level. The number of strut levels depends on the excavation depth.

04. Construction of Underground Structure

At formation level, the reinforced concrete slab or base slab is constructed, followed by the removal of the lowest level strut and the side walls are constucted

05. Construction of Underground Structure

The next level of slab is constructed, followed by the removal of the strut near to that slab level. This process progresses upwards till the roof slab is constructed.

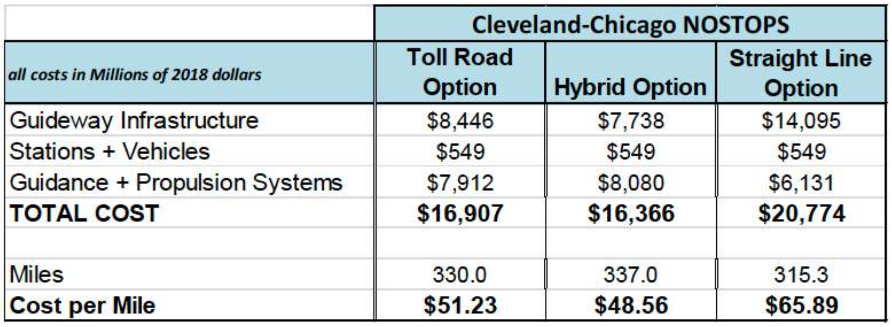
06. Backfilling & Reinstatement

After the roof slab is completed, the soil is backfilled to the first strut level before the first level strut is removed. This is followed by completely backfilling the top of the underground structure. If the retaining wall is a diaphragm wall or a bored pile wall, the top 2 metres of the wall will be removed. If it is a sheet pile wall, the sheet piles will be extracted.

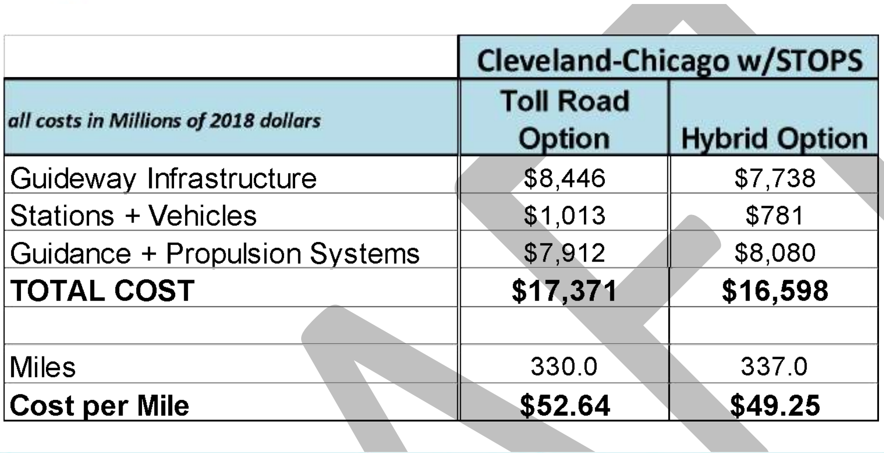
7.3 Capital Cost Results

Exhibit 7-6 summarizes overall capital costs for each route segment and option. Cleveland to Chicago costs are based on the full route option, whereas a segment-level breakdown is given for the optional extensions from Cleveland to Youngstown and ultimately to Pittsburgh. All costs include a 30% contingency and 28% soft-costs factor.

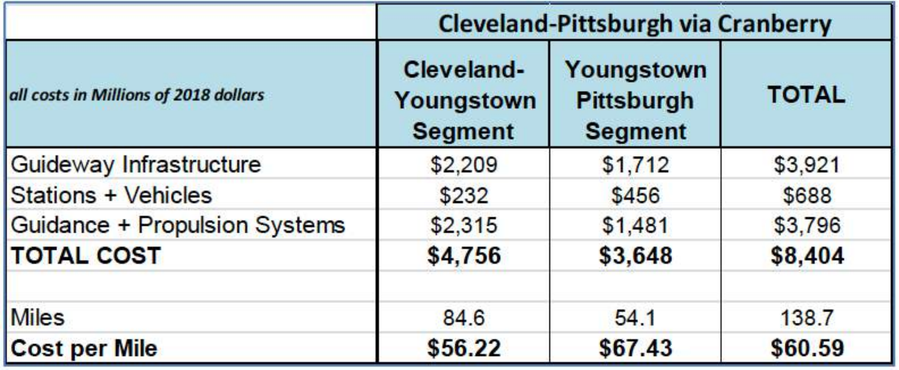
Exhibit 7-6: Hyperloop Capital Costs by Segment (All costs in Millions of 2018 US dollars)



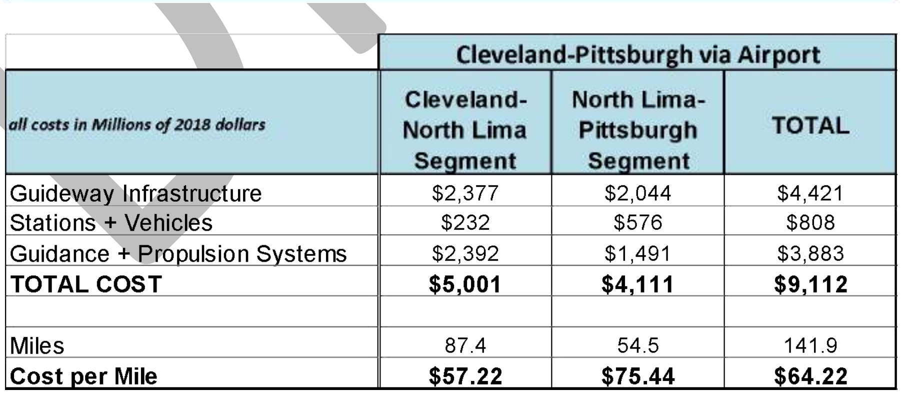
	Cleveland-Chicago NOSTOPS		
all costs in Millions of 2018 dollars	Toll Road Option	Hybrid Option	Straight Line Option
Guideway Infrastructure	$8,446	$7,738	$14,095
Stations + Vehicles	$549	$549	$549
Guidance + Propulsion Systems	$7,912	$8,080	$6,131
TOTAL COST	**$16,907**	**$16,366**	**$20,774**
Miles	330.0	337.0	315.3
Cost per Mile	**$51.23**	**$48.56**	**$65.89**



	Cleveland-Chicago w/STOPS	
all costs in Millions of 2018 dollars	Toll Road Option	Hybrid Option
Guideway Infrastructure	$8,446	$7,738
Stations + Vehicles	$1,013	$781
Guidance + Propulsion Systems	$7,912	$8,080
TOTAL COST	**$17,371**	**$16,598**
Miles	330.0	337.0
Cost per Mile	**$52.64**	**$49.25**



	Cleveland-Pittsburgh via Cranberry		
all costs in Millions of 2018 dollars	Cleveland-Youngstown Segment	Youngstown Pittsburgh Segment	TOTAL
Guideway Infrastructure	$2,209	$1,712	$3,921
Stations + Vehicles	$232	$456	$688
Guidance + Propulsion Systems	$2,315	$1,481	$3,796
TOTAL COST	**$4,756**	**$3,648**	**$8,404**
Miles	84.6	54.1	138.7
Cost per Mile	**$56.22**	**$67.43**	**$60.59**



	Cleveland-Pittsburgh via Airport		
all costs in Millions of 2018 dollars	Cleveland-North Lima Segment	North Lima-Pittsburgh Segment	TOTAL
Guideway Infrastructure	$2,377	$2,044	$4,421
Stations + Vehicles	$232	$576	$808
Guidance + Propulsion Systems	$2,392	$1,491	$3,883
TOTAL COST	**$5,001**	**$4,111**	**$9,112**
Miles	87.4	54.5	141.9
Cost per Mile	**$57.22**	**$75.44**	**$64.22**

Chapter 8

Operating Costs

Summary

Operating costs were calculated for each year the system is planned to be operational using operating cost drivers such as passenger volumes, capsule miles, and operating hours. The aim is to develop an affordable set of options that provide good service at a reasonable cost.

8.1 Operating Cost Methodology

This section describes the development of unit operating costs, that will be used in conjunction with the operating plans for assessing total operating cost for HyperloopTT's Great Lakes corridor. Since a commercial Hyperloop is not yet in operation, costs have been developed based on engineering calculations, benchmarks of previous High-Speed Ground transportation studies, and in consultation with HyperloopTT.

An operations costing framework that was originally developed for high-speed ground transportation systems was adapted for use in this study. The framework[23] is well-accepted and understood for feasibility level planning studies. This same framework had earlier been used for many studies (such as RMRA[24]) so many of the costs used here have been adjusted from these earlier studies. As shown in Exhibit 8-1, following this methodology, eight specific cost areas have been identified:

- Variable costs include equipment maintenance, energy and fuel, and crews. Passenger miles drive insurance liability costs, while Ridership influences marketing, and sales expenses.
- Fixed costs include overhead administrative costs, station costs, and guideway operating and maintenance costs. Command, Control, Communications, and Information (C3I or signaling) costs including the power supply system are included in the fixed per-mile costs for guideway maintenance and operation.

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[23] Follow links under "Midwest Regional Rail Initiative (MWRRI)" at http://www.dot.state.mn.us/planning/railplan/studies.html

[24] Rocky Mountain Rail Authority, at http://rockymountainrail.org/RMRA_Final_Report.html

Exhibit 8-1: Operating Cost Categories and Primary Cost Drivers

Drivers	Cost Categories
Capsule Miles	Equipment Maintenance Energy Onboard Crews
Passenger Miles	Insurance Liability
Ridership / Revenue	Sales and Marketing
Fixed Cost	Service Administration Guideway Operations Station Costs

Unit costs in this analysis were developed from primary sources or based on previous studies or benchmarks. Costs specific to Hyperloop, such as energy usage and equipment maintenance, were established in consultation with HyperloopTT, but were also correlated with outside benchmarks, such as local energy prices and public studies of Hyperloop energy efficiency. The cost development approach focused on fine-tuning those items having the greatest impact on the bottom line. All costs are based on second generation Hyperloop technology, which reflects a level of technological maturity that is intended to be deployed in service for the Great Lakes Hyperloop.

- Operating costs can be categorized as variable or fixed. As described below, fixed costs include both Route and System overhead costs. Route costs can be clearly identified to specific services but do not change much if fewer or additional capsules were operated.
- Variable costs change with the volume of activity and are directly dependent on ridership, passenger miles or capsule miles. For each variable cost, a principal cost driver is identified and used to determine the total cost of that operating variable. An increase or decrease in any of these will directly drive operating costs higher or lower.
- Fixed costs are generally predetermined, but may be influenced by external factors, such as the volume of freight tonnage, or may include a relatively small component of activity-driven costs. As a rule, costs identified as fixed should remain stable across a broad range of service intensities. Within fixed costs are two sub-categories:
    - Route costs such as guideway maintenance, capsule control and station expense that, although fixed, can still be clearly identified at the route level.
    - Overhead or System costs such as headquarters management, call center, accounting, legal, and other fixed costs that are shared across routes or even nationally. A portion of overhead cost (such as direct line supervision) may be directly identifiable but most of the cost is fixed. Accordingly, assignment of such costs becomes an allocation issue that raises equity concerns. These kinds of fixed costs are handled separately.

The analysis has been conducted using 2019 constant dollars.

8.2 Variable Costs

These costs include those that directly depend on the number of capsule-miles operated or other direct drivers, such as ridership or revenue. They include equipment maintenance, crew cost, energy, onboard service, and insurance costs.

8.2.1 Capsule Maintenance

Equipment maintenance costs include all costs for spare parts, labor and materials needed to keep equipment safe and reliable. The costs include periodic overhauls in addition to running maintenance. It assumes efficient and cost-effective maintenance practices. Acquiring a large fleet of capsules with identical features and components, allows for substantial savings in parts inventory and other economies of scale. In particular, commonality of equipment would standardize maintenance training, enhance efficiencies and foster broad expertise in system repair.

8.2.2 Capsule Crew Costs

Since the Hyperloop operating environment will be totally isolated, it is possible to fully automate the system. It could be possible to eliminate staffing on-board capsules and instead place staffing in stations. However, any intercity passenger service needs safety, fare collection and customer service functions that can be performed by an on-board capsule crew. This study will conservatively assume that each passenger capsule is staffed by one crew member who will mostly serve a safety function, as well as to provide customer service. Only freight capsules would operate without staffing. Costs for a crew member on each capsule must include salary, fringe benefits, training, overtime and additional pay for split shifts. An overtime allowance must be included as well as scheduled time-off, unscheduled absences and time required for operating, safety and training. Fringe benefits include health and welfare, workman's compensation and pensions. The cost of employee injury claims under workman's compensation is also treated as a fringe benefit for this analysis. Assuming that Hyperloop personnel will be paid similarly to airline and rail staff, an overall fringe benefit rate has been estimated as 55 percent. In addition, an allowance is made for reserve crews.

8.2.3 Energy

Energy costs for both the ridership forecast and operating cost models are based on a consistent set of energy costs. The ridership demand model calibration was based on oil and gasoline energy costs that were historically in effect during the base year of 2018. For future years cost projections for auto, air and Hyperloop are all based on Energy Information Administration (EIA)[25] forecasts. However, Hyperloop will use electricity for its power, so it can be powered from any energy source, not just petroleum-based fuel. Historically, electricity costs have been much more stable than oil prices, which are subject to many short-term supply and demand issues.

Drag is friction on movement of the vehicle. This energy is forever lost and will appear in the guideway in the form of heat. It cannot be recovered in useful form. However, energy that is used for accelerating the vehicle is stored in the vehicle as kinetic energy and can potentially be recovered when the vehicle slows down. Because of the large amount of energy imparted to Hyperloop's high-speed capsules, an allowance must be made for energy recapture during regenerative braking. That is, most of the energy used while accelerating can be recovered while braking and fed back into the electric system. Like other kinds of maglev vehicles, the proposed Hyperloop capsules will have the ability for regenerative braking. Because of the high vacuum (10 Pa), the air resistance is practically negligible, and magnetic drag declines as speeds increase. This leads to the rather counterintuitive conclusion that the faster Hyperloop goes, the greater its energy efficiency. It has been estimated that the Lift-to-Drag ratio of the highly

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[25] EIA retail prices excluding the taxes http://www.eia.gov/petroleum/gasdiesel/

efficient Inductrak II guideway could approach 2000:1 at Hyperloop speeds. However, for this analysis and for consistency with a U.S. Department of Energy study now underway, a much more conservative Lift-to-Drag ratio of just 200:1 has been assumed.

8.2.4 Onboard Services (OBS)

Onboard service (OBS) costs are those expenses for providing food service onboard the capsules. OBS adds costs in three different areas: equipment, labor and cost of goods sold. Equipment capital and labor cost is built into the cost of the capsules and is not specifically attributed to food catering. It is assumed that the capsule attendant would offer food and beverages for sale to the passengers as airlines do. For first class service, it is possible that no revenues would be collected directly but rather would be attributed as part of the ticket price. If an on-board employee were needed for safety reasons (as they are for airlines) then this customer service amenity can be provided at very little additional cost, basically just the cost of the food. This would probably be provided by a contracted caterer, such as Gate Gourmet who specializes in providing similar catering services to airlines.

8.2.5 Insurance Costs

Hyperloop Transportation Technologies (HyperloopTT) and leading global insurer Munich Re have carried out a comprehensive risk analysis of HyperloopTT's Hyperloop technology and have declared it feasible and insurable[26]. The Munich Re analysis constitutes a critical milestone for the future success of the HyperloopTT system, since the system design inherently eliminates many of the risks associated with operation of today's transport systems. Since it will operate in a completely controlled environment, weather-related risks associated with today's aviation system will be completely eliminated. Also, collision-related risks associated with today's surface transportation systems operating in an uncontrolled environment, such as the risk associated with highway railroad grade crossings, will also be eliminated.

On this basis it was considered that the insurance cost would be comparable to or lower than the costs of today's High-Speed Ground transportation modes. Because of the considerable safety improvement associated with HyperloopTT system this treatment is considered conservative for this analysis.

8.3 Fixed Route Costs

This cost category includes those costs that, while largely independent of the number of capsule-miles operated, can still be directly associated to the operation of specific routes. It includes such costs as guideway maintenance and station operations.

8.3.1 Guideway and Right-of-Way Costs

The following cost components will be included within the Guideway and Right-of-Way category:

- **Guideway Maintenance Co**sts. Costs for guideway maintenance include costs for maintaining the guideway, power and propulsion, safety, and signaling (3CI) systems in good working order.
- **Costs for Access to Right-of-Way**. If right-of-way is acquired by lease or easement rather than by outright purchase, then the ongoing lease costs may be reflected as an operating expense.
- **Vacuum and Tube System**. This will include operating (primarily energy) and maintenance costs associated with the Vacuum system.

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[26] Hyperloop Transportation Technologies Collaborates with Munich Re to Insure Hyperloop, https://www.prnewswire.com/news-releases/hyperloop-transportation-technologies-collaborates-with-munich-re-to-insure-hyperloop-300537989.html

These costs have been developed in consultation with HyperloopTT.

8.3.2 Station Operations

A simplified fare structure and a heavy reliance upon electronic ticketing and internet booking will minimize station personnel requirements. Station costs include personnel, ticket machines and station operating expenses.

- All stations were assumed open for two shifts.
- Stations also have significant operating cost for maintenance, lighting, heating and ventilation and for escalator maintenance for underground and/or fully enclosed surface level major stations.

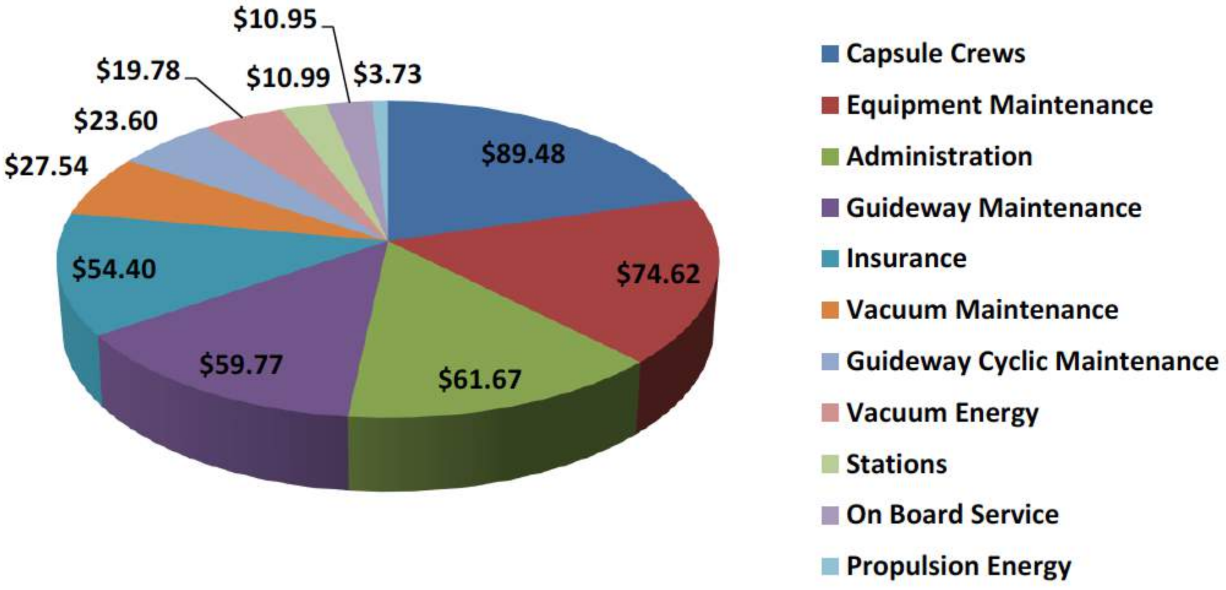
8.4 System Overhead Costs

The category of System Overhead largely consists of Service Administration or management overheads, covering such needs as the corporate procurement, human resources, accounting, finance and information technology functions as well as call center administration. A stand-alone administrative organization appropriate for the operation of a corridor system has been developed for use in regional and high-speed rail studies.

8.5 Operating Cost Summary

Exhibit 8-2 summarizes the overall 2030 Passenger operating costs for the Great Lakes Hyperloop corridor. While these costs have all been agreed to by Hyperloop Transportation Technologies (HyperloopTT) as reasonable for the purpose of this study, they were all estimated from public sources. These costs are subject to review and refinement in more detailed next step studies.

Exhibit 8-2: Hyperloop 2030 Passenger Operating Costs (2018 dollars)



These results show that the cost of providing capsule crews will be the largest single operating expense since obviously, this will need to be provided by using human labor whereas the operation of most of the rest of the HyperloopTT system is highly automated.

Conversely, propulsion energy is very low due to the practical elimination of air drag, the assumption of a 200:1 Lift to Drag ratio associated with second-generation Inductrak technology, and the full use of regenerative braking as enabled by the use of conservative (0.1 G) braking curves. The overall level of costs results in an average cost of \$6.10 per capsule mile, or 12.2¢ per seat-mile in 2030.

Chapter 9

Financial and Economic Analysis

Summary

This chapter presents a detailed financial and economic analysis for the Great Lakes Hyperloop. A detailed Economic Analysis was carried out using the Public-Private Partnership criteria set out by the 1997 FRA Commercial Feasibility Study including key economic measures such as NPV Operating Surplus and Benefit/Cost Ratio at a three and seven percent discount rate which are also presented in this chapter. It is anticipated that Hyperloop will be developed within the framework of a Public-Private Partnership as appropriate to the financing and funding of the project.

9.1 Introduction

Two measures, Operating Ratio and Benefit Cost ratio will be assessed here to evaluate the financial and economic returns of the Great Lakes Hyperloop. The financial performance of the system, reflected by the Operating Ratio, is a key driver of the financial evaluation since it strongly influences the ability to franchise the operation of the system to the private sector. ***System Revenues*** include the farebox revenues and revenues from onboard sales. ***Operating Costs*** are the operating and maintenance costs associated with running the train. The Operating Ratio is defined as Revenues/Costs and as calculated here includes direct operating costs only. Operating ratio calculations do not include capital costs, depreciation or interest.

By this analysis, a positive operating ratio does not imply that a system can fully cover its capital costs but having a positive cash flow does at least allow the operation to be franchised and run by the private sector. This requirement of the FRA *Commercial Feasibility Study* puts Hyperloop on an equitable basis with other modes of transportation, such as intercity bus and air, where the private sector operates the system but does not build or own the infrastructure it uses. Other modes do pay for terminals and access fees for using the public infrastructure, which supports some cost recovery which varies by mode. All calculations are performed using standard financial formulas, as follows:

Present Value is defined as:

$$PV = \sum_t \frac{C_t}{(1+r)^t}$$

Where:

PV = Present value of all future cash flows

C_t = Cash flow for period t

r = A given discount rate reflecting the opportunity cost of money

t = Time

NPV and IRR:

Net Present Value = Present Value of Benefit – Present Values of Costs

IRR = The interest rate r that results in a Net Present Value of zero

Financial Measure:

$$\text{Operating Ratio} = \frac{\text{Financial Revenues (by year or PV)}}{\text{Operating Costs (by year or PV)}}$$

Economic Measures:

$$\text{Benefit Cost Ratio} = \frac{\text{Present Value (PV) of All Benefits}}{\text{Present Value (PV) of All Costs}}$$

As a financial measure, Operating Ratios can be presented either on a specific year-to-year basis, or they can be summarized based on the discounted values of operating revenue and operating cost, and presented as a single number for the entire life of the project. Operating Ratios provide a direct comparison of project revenues to project costs. To develop financial IRR's or NPV's, capital costs are added and included in the financial discounting process. An IRR calculation can be performed by finding the interest rate that sets the financial NPV to zero.

- If the operating surplus is positive, the system will not require any operating subsidy, and it will even be able to make a contribution towards its own Capital cost. Because the system is generating a positive cash flow, a Private-Public Partnership or other innovative financing methods can be used to construct and operate the system. This absolves the local governmental entity of any need for providing an operating subsidy but more than this, it is not uncommon for the operating cash flow to be sufficient to cover the local capital match requirement as well.

- If the operating surplus is negative, the system will not only require a grant of capital to build the system, but in addition it will also require an ongoing operating subsidy. An operating subsidy not only prevents the project from being a Public Private Partnership, but casts doubt on the efficiency of the system and the reason for the project. In addition, a subsidy will reduce the economic performance of the system as it will actually offset part of the economic benefits of the system (e.g. Consumer Surplus, Environmental Benefits). This will depress the Benefit Cost ratio as well. If the subsidy is not too great and the capital cost is not too high, in some cases it may still be possible to maintain a positive Benefit Cost ratio. But the larger the subsidy and the higher the capital cost, the harder it is to show a positive Benefit Cost ratio. It is not uncommon for slow passenger rail to fail both of USDOT's Operating Ratio and Benefit Cost criteria.

As an economic measure, calculating a Benefit-Cost ratio requires the development of a project's year-by-year economic returns, which are then discounted to the base year to estimate present values (PV) over the lifetime of the project. In terms of Economic Benefits, a positive NPV and Benefit Cost Ratio greater than one imply that the project makes a positive contribution to the economy. Consistent with standard practice, Benefit-Cost ratios are calculated from the perspective of the overall society without regard to who owns particular assets receives specific benefits or incurs particular costs.

For Benefit-Cost analysis, Net Present Values (NPV's) must be calculated at a 3% and 7% REAL interest rate, as according to the requirements of the Office of Management and Budget (OMB) Circular A-94. Since Inflation has been running a little over 2% per year, this OMB requirement is equivalent to a nominal interest rate of 5% to 9% per year. However, Moody's Seasoned AAA Corporate Bond Yield was just 3.82% (nominal) in March 2019. Therefore, corporate bonds are offering only about a 1.6-1.8% real return. As a result, it can be seen that even the 3% discount rate (real) is higher than current market rates. The very high 7% REAL rate required by OMB can only be characterized as a rationing rate of interest.

9.2 Financial Measures

A financial evaluation has been completed for several options as described below. Each evaluation follows typical financial/economic cash flow protocols, USDOT-Tiger Grant guidelines, and OMB discount procedures for the economic analysis. The analysis was completed using data derived from the Ridership and Revenue Analysis, Infrastructure Analysis, and the Operating Analysis.

The Financial Analysis includes the following **Revenue Items:**

- **Passenger Revenue:** Forecasted Farebox Revenue
- **Express Parcel Net:** This is a net amount of revenue accruing to the Hyperloop operator *after* courier pickup and delivery fees and other costs have been deducted. Because this business is handled on board existing passenger capsules, it has very little direct operating cost associated with it. These revenues go straight to the bottom line.
- **Real Estate Net:** Similarly, this a net amount of revenue accruing to the Hyperloop operator *after expenses* for the net annual revenues associated with real estate joint development. These revenues go straight to the bottom line.
- **Air Cargo Revenue:** This is a revenue estimate for Hyperloop's share of the air cargo market. Because this business requires the operation of dedicated freight capsules, it has direct expenses associated with it that offset part of this revenue.
- **LTL Cargo Revenue:** This is a revenue estimate for Hyperloop's share of the LTL ground freight market. Because this business requires the operation of dedicated freight capsules, it has direct expenses associated with it that offset part of this revenue.

On the cost side, the Financial Analysis includes:

- **Passenger Operating Cost:** This is Hyperloop's cost associated with operating the passenger service. It includes guideway, vehicle and station maintenance, energy and operating cost. This cost is reported here at an aggregate level.
- **Diverted Air Cargo Operating Cost:** This is Hyperloop's cost associated with handling the air cargo freight. It is calculated incrementally to passenger service and mainly focuses on capsule maintenance, operating and energy cost as well as an allowance for freight terminal costs. This analysis treats guideway cost as essentially fixed and therefore treats both air cargo and LTL cargo as the incremental users of the guideway.

Therefore, the cost analysis focuses mostly on added vehicle and freight terminal operating costs, that would not need to be incurred but for the incremental cargo operations.

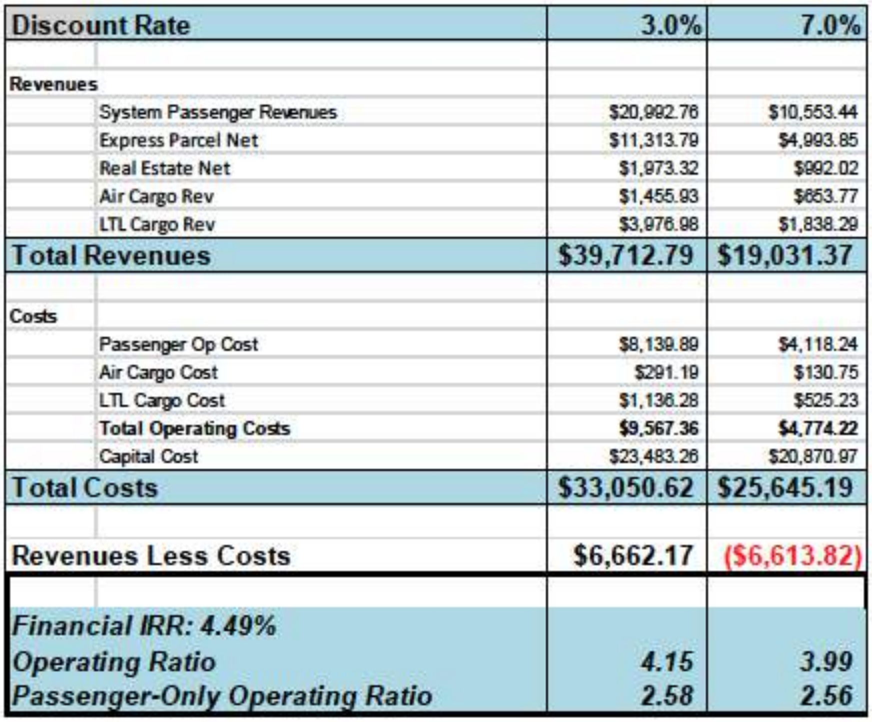
- **Diverted LTL Cargo Operating Cost:** This is Hyperloop's cost associated with handling the LTL ground freight. It is calculated incrementally to passenger service and mainly focuses on capsule maintenance, operating and energy cost as well as an allowance for freight terminal costs.
- **Capital Costs:** These are included in the IRR and Financial NPV calculations, but not in the Operating Ratio.

As previously described, the ratio of Revenues divided by Costs defines the operating ratio for the project. If the operating ratio is greater than 1.00 then the project will generate a positive cash flow, will not need an operating subsidy and can make at least some level of contribution towards funding its own capital costs. By generating a positive cash flow, the operations of the system could be franchised to a private operator. The IRR calculation provides a measure of the financial return and the consequent ability of the private sector to contribute capital to the project.

Exhibit 9-1 shows the financial results for the Great Lakes Hyperloop from Chicago to Pittsburgh. From Cleveland to Chicago this assessment is based on the Toll Road option, which is the best performing alternative for that segment of the route. From Cleveland to Pittsburgh in conjunction with the Toll Road, the two available alternatives (via Cranberry or via the Airport) perform very similarly, although it appears that the Airport option is slightly better from both a Cost Benefit and Financial point of view. The financial NPV of both options is positive at 3% but negative at 7%. As a result, the Internal Rates of Return will lie between these extremes. The IRR of the Cranberry option has been estimated at 4.49% and for the route via the airport the IRR is 4.61%.

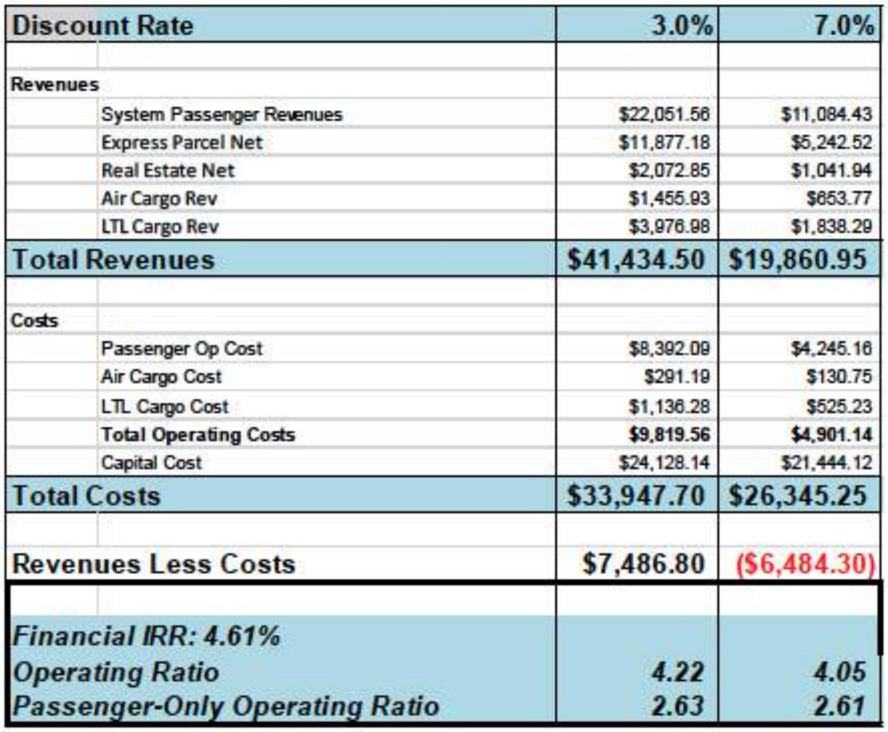
Exhibit 9-1: Great Lakes Hyperloop - Financial Results for Cleveland-Chicago Toll Road with:

(a) Pittsburgh via Cranberry



Discount Rate		3.0%	7.0%
Revenues			
	System Passenger Revenues	$20,992.76	$10,553.44
	Express Parcel Net	$11,313.79	$4,993.85
	Real Estate Net	$1,973.32	$992.02
	Air Cargo Rev	$1,455.93	$653.77
	LTL Cargo Rev	$3,976.98	$1,838.29
Total Revenues		**$39,712.79**	**$19,031.37**
Costs			
	Passenger Op Cost	$8,139.89	$4,118.24
	Air Cargo Cost	$291.19	$130.75
	LTL Cargo Cost	$1,136.28	$525.23
	Total Operating Costs	**$9,567.36**	**$4,774.22**
	Capital Cost	$23,483.26	$20,870.97
Total Costs		**$33,050.62**	**$25,645.19**
Revenues Less Costs		**$6,662.17**	**($6,613.82)**
Financial IRR: 4.49%			
Operating Ratio		***4.15***	***3.99***
Passenger-Only Operating Ratio		***2.58***	***2.56***

(b) Pittsburgh via Airport



Discount Rate		3.0%	7.0%
Revenues			
	System Passenger Revenues	$22,051.56	$11,084.43
	Express Parcel Net	$11,877.18	$5,242.52
	Real Estate Net	$2,072.85	$1,041.94
	Air Cargo Rev	$1,455.93	$653.77
	LTL Cargo Rev	$3,976.98	$1,838.29
Total Revenues		**$41,434.50**	**$19,860.95**
Costs			
	Passenger Op Cost	$8,392.09	$4,245.16
	Air Cargo Cost	$291.19	$130.75
	LTL Cargo Cost	$1,136.28	$525.23
	Total Operating Costs	**$9,819.56**	**$4,901.14**
	Capital Cost	$24,128.14	$21,444.12
Total Costs		**$33,947.70**	**$26,345.25**
Revenues Less Costs		**$7,486.80**	**($6,484.30)**
Financial IRR: 4.61%			
Operating Ratio		***4.22***	***4.05***
Passenger-Only Operating Ratio		***2.63***	***2.61***

9.3 Economic Results

The demand side Economic Analysis identifies Non-Cash External Benefits that are required for the Cost Benefit analysis:

- **Consumer Surplus:** This is the value received by the passengers primarily due to value of time savings. Since most High-Speed Ground Transportation systems charge a fare, this has the effect of reducing the Consumer Surplus to a level lower than it would be if no fare were charged.
- **Freight Environmental Benefit:** This is an estimate of the non-user external benefits in terms of emissions reduction, pavement damage reduction, and congestion relief associated with having fewer trucks on the highway.
- **Environmental + Resource Benefit (Air):** This is an estimate of the value of emissions and non-user congestion time savings associated with reduced air traffic and reduced airline delays
- **Environmental + Resource Benefit (Auto**): This is an estimate of the value of emissions and non-user congestion time savings associated with reduced passenger automobile use

On the cost side, the Economic Analysis includes:

- **Operating Cost:** This is Hyperloop's cost associated with operating the passenger service. It includes guideway, vehicle and stations maintenance, energy and operating cost. This cost is reported here at an aggregate level. This operating cost is broken into passenger, air cargo and LTL cargo related operating cost, as described previously.
- **Capital Cost:** This is the capital cost associated with constructing the system. It has to be amortized over the life of the assets. All costs are accounted for on cash basis for discounting purposes and are divided across the implementation years of the system. Depreciation and financing costs are not included since a discounted cash flow methodology is being used.

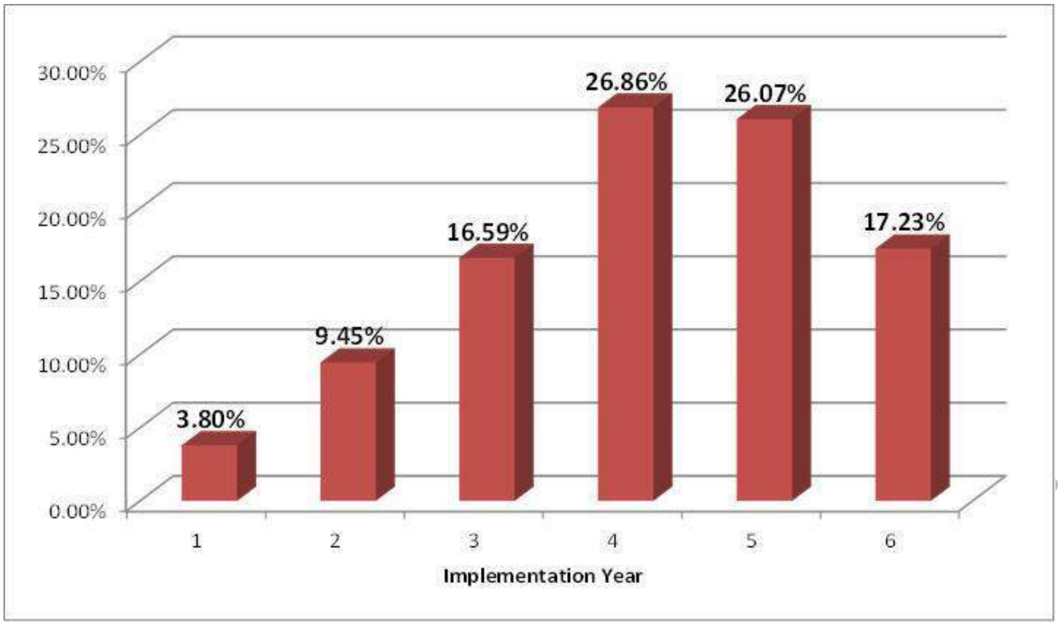
9.3.1 Key Assumptions

The analysis assumes project construction from 2024 through 2028, and then forecasts travel demand, operating revenues and operating and maintenance costs from 2029 through 2059. The financial analysis has been conducted in ***real*** terms using constant 2018 dollars. Accordingly, no inflation factor has been included, and ***real*** discount rate of 3 and 7 percent have been used. Revenues and operating costs have also been projected in constant dollars over the time frame of the financial analysis. A summary of the key efficiency measure inputs are presented below.

9.3.1.1 Capital Costs

Capital costs include vehicle, guideway, right-of-way purchase or easement fees, bridges, control systems, maintenance facilities and stations. The capital cost projections are based on year-by-year projections of each cost element. A year-by-year implementation plan was developed which detailed the Capital cash flows for each option. Using this information, Benefit Cost calculations were able to be assessed. For the purpose of this study it is assumed that the Capital Costs will be spent over a six-year period with the distribution shown in Exhibit 9-2. Over 85 percent of funds are spent in the last four years of the implementation period as construction occurs. Once major construction starts, it is of benefit to the economic result to complete the system and start operations. This way the benefit stream can start to offset the capital costs as soon as possible, which is of benefit in the NPV discounting process.

Exhibit 9-2: Assumed Capital Spend Distribution



9.3.1.2 Operating Expenses

Major operating and maintenance expenses include equipment maintenance, guideway and right-of-way maintenance, administration, energy, crew and other relevant expenses. Operating expenses were estimated in 2018 constant dollars so they would remain comparable to revenues. However, these costs do reflect the year-by-year increase in expense that is needed to handle the forecasted ridership growth, in terms of not only directly variable expenses such as credit card commissions, but also the need to add vehicle capacity and operate either larger capsules, or more capsule-miles every year in order to accommodate anticipated ridership growth.

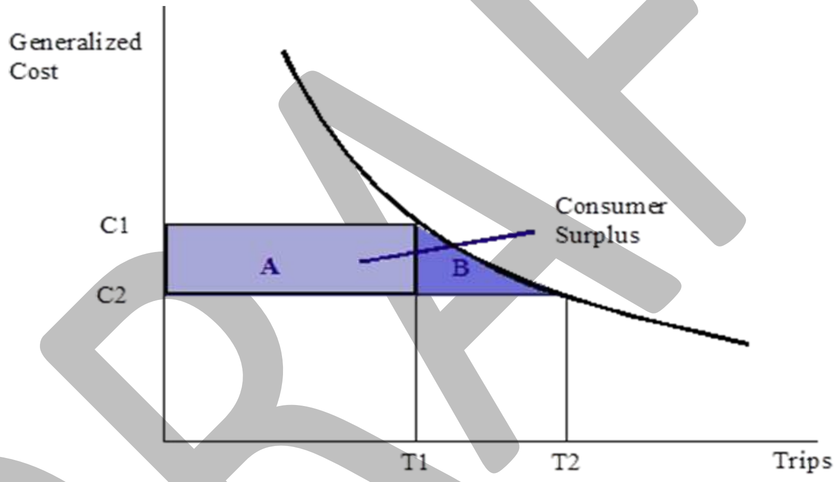
9.3.1.3 User Benefits

The analysis of user benefits for this study is based on the measurement of Generalized Cost of Travel, which includes both time and money. Time is converted into money by the use of Values of Time. Since the current feasibility study did not provide for new Stated Preference data to be collected, the Values of Time (VOT) used in this study were derived from stated preference surveys conducted in the earlier High-Speed ground transportation studies conducted by TEMS, and were used in the COMPASS™ Multimodal Demand Model for the ridership and revenue forecasts. These VOTs are consistent with previous academic and empirical research and other transportation studies conducted by TEMS. Most likely a new Stated Preference data collection will need to be developed if this project moves ahead into the Environmental Planning phase.

Consumer Surplus: Consumer surplus is produced by the COMPASS™ model at the same time as the revenue forecasts are produced. Ridership and revenue forecasts were originally prepared for 2020, 2030, and 2050. Revenues in intervening years were projected based on interpolations, reflecting projected annual growth in ridership, and trend line extrapolation out to 2059. Consumer surplus is used to measure the demand side impact of a transportation improvement on users of the service. It is defined as the additional benefit consumers (users of transportation services) receive from the purchase of a commodity or service (travel), above the price actually paid for that commodity or service. In simplistic terms, it would include the value of any time savings benefit to system users, but COMPASS™ precisely calculates it based on the shape of the calibrated demand curves. Consumer surpluses exist because there are always consumers who are willing to pay a higher price than that actually charged for the commodity or service, i.e., these consumers receive more benefit than is reflected by the system revenues alone. The benefits apply to existing travelers as well as new travelers who are induced (those who previously did not make a trip) or diverted (those who previously used a different mode) to the new passenger system.

The RENTS™ economic analysis estimates passenger travel benefits (consumer surplus) by calculating the increase in regional mobility, traffic diverted, and the reduction in travel cost measured in terms of generalized cost for existing users. The term generalized cost refers to the combination of time and fares paid by users to make a trip. A reduction in generalized cost generates an increase in the passenger user benefits. A transportation improvement that leads to improved mobility reduces the generalized cost of travel, which in turn leads to an increase in consumer surplus. Exhibit 9-3 presents a typical demand curve in which Area A represents the increase in consumer surplus resulting from cost savings for existing users and Area B represents the consumer surplus resulting from induced traffic and trips diverted to the system.

Exhibit 9-3: Consumer Surplus Concept



The formula for consumer surplus is as follows –

Consumer Surplus = $(C_1 – C_2)$*T1 + $((C_1 – C_2)$*$(T_2 – T_1))/2$

Where:

C_1 = Generalized Cost users incur before the implementation of the system

C_2 = Generalized Cost users incur after the implementation of the system

T_1 = Number of trips before operation of the system

T_2 = Number of trips during operation of the system

The passenger fares used in this analysis are the fares derived from applying a fare discount to the optimized fare, to reduce fares to the lowest level possible without significantly reducing revenues. Moderating fares in this way increases the forecasted ridership, and also increases both consumer surplus and the external mode benefits, as described in the next section.

9.3.1.4 Non-User Benefits

In addition to user benefits, travelers using auto or air will also benefit from the investment, since the system will contribute to highway congestion relief, and will reduce delays and travel times for users of these other modes. For purposes of this analysis, these benefits were measured by identifying the estimated number of auto and air passenger trips that benefited due to the lower number of passengers using them than would be the case if the HyperloopTT system were not operational.

Highway Congestion: The highway congestion delay savings is the time savings to the remaining highway users that results from diversion of auto users to the Hyperloop. To estimate travel time increase within the corridor, historical highway traffic volumes were obtained from the State DOTs and local planning agencies. The average annual travel time growth in the corridor was estimated with the historical highway traffic volume data and the BPR (Bureau of Public Roads) function that can be used to calculate travel time growth with increased traffic volumes.

Airport Congestion Delay Savings: Airport Congestion Delay Savings include the airport operation delay saving and air passenger delay saving. It should be noted at both Cleveland and Pittsburgh, that the Hyperloop system is projected to divert a number of trips, but these are concentrated currently only towards Chicago, whereas the airports serve many other destinations as well. Therefore, the analysis projects a reduction of a few Cleveland-Chicago and Pittsburgh-Chicago flights. Therefore, implementation of the Hyperloop will result in minor diversion of air traffic to Hyperloop which, nonetheless, will produce some congestion and delay savings, primarily in Chicago.

Auto Operating Cost (Non-Business): Vehicle operating cost savings for non-business travelers have been included in the current analysis as an additional resource benefit. This reflects the fact that social/leisure travelers do not accurately value the full cost of driving when making trips. As a result, the consumer surplus calculation for commuters, social, leisure and tourist travelers has not fully reflected the real cost of operations of an automobile, but only the cost of gas. The difference between the cost of gas and the full cost of driving reflects a real savings that should be included in a Benefit Cost analysis.

Emissions: The diversion of travelers to Hyperloop from the auto mode generates emissions savings. The calculated emissions savings are based on changes in energy use with and without the proposed service. This methodology takes into account the region of the country, air quality regulation compliance of the counties served by the proposed service, the projection year, and the modes of travel used for access/egress as well as the line-haul portion of the trip. Highway Reduced Emissions were estimated from the vehicle miles traveled (VMT) and flight reductions derived from the ridership model, however there were no forecasted reductions in airline flights. The assumption is that a reduction in VMT or flights is directly proportional to the reduction in emissions. The pollutant values were taken from the TIGER III Grant Benefit-Cost Analysis (BCA) Resource Guide[27] as well as the latest BUILD grant guidance.

Public Safety Benefits: Public Safety is calculated from the diverted Vehicle-Miles times the NHTSA[28] fatality and injury rate per Vehicle mile and then times the values of fatality and injury from the latest TIGER III Grant Benefit-Cost Analysis (BCA) Resource Guide.

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[27] http://www.dot.gov/sites/dot.dev/files/docs/TIGER_BCA_RESOURCE_GUIDE.pdf

[28] http://www.nhtsa.gov/

9.4 Economic Results

A number of variations on Hyperloop implementation options were assessed as sensitivities. Following OMB guidelines, Benefit Cost ratios for all the options were assessed at both 3% interest as well as the required rationing interest rate of 7%. A positive result (Benefit Cost ration >1) at 7% would meet FRA's requirements that a project must be able to demonstrate a favorable Benefit Cost return. The economics of the project were assessed in three "layers":

1. The first "layer" consisted of non-stopping direct Cleveland to Chicago alternatives. Three different route alternatives that had different capital costs were assessed, but the ridership of any of the three alternatives was very similar.
2. The second "layer" added intermediate stops at Toledo and South Bend, and for this purpose, also considered a possible eastward extension to Youngstown. It should be noted that the intermediate stations were always considered as "off line" stations so that any direct express capsules would not have to stop at the intermediate stations. Intermediate stations could be added at Toledo and South Bend without adding any stops to the through Cleveland-Chicago capsules. As a result, ridership and revenue grow as more stations are added, and this could be done without delaying through services in any way.
3. The third and final "layer" added an eastward extension to Pittsburgh while still retaining the traffic and revenues from the intermediate stations of layer 2.

9.4.1 Non-Stop Alternatives

Non-Stop Alternatives generate approximately 3 million riders per year and 270,000 tons of freight in 2030. They are all very similar in ridership performance. This results in an average of 120 (50 person) passenger capsules per day each way plus 27 freight capsules, a total of 147 capsules per day. Assuming a very conservative headway of 2 minutes for 16 hours, the guideway would have capacity for 480 capsules each way. As a result, this utilizes only 147/480 = 31% of the guideway capacity. As shown in Exhibit 9-4, the Straight Line option has the best Operating Ratio but also the highest Capital Cost. As a result, it fails the BCR requirements at both 3% and 7% ROI. The Hybrid and Toll Road non-stop options can develop a BCR > 1.0 at 3% but because of low guideway capacity utilization are not able to pass the 7% BCR hurdle.

9.4.2 Alternatives with Intermediates

Adding intermediate stations at Toledo and South Bend would result in a considerable boost in the system ridership and revenue. Toledo would add about 2 million riders, while South Bend would add about 1.7 million riders. For the Cleveland to Chicago Toll Road option this results in an average of 270 (50 person) passenger capsules per day each way plus 40 freight capsules, a total of 310 capsules per day. As a result, this utilizes only 310/480 = 65% of the guideway capacity. As shown in Exhibit 9-5, the Toll Road options have the best Operating Ratio because they have the highest revenue and ridership. This is because the Toll Road option includes South Bend, whereas the Hybrid option bypasses South Bend on a more southerly alignment. While the Cleveland to Chicago Toll Road is the best performing option, it is still not quite able to pass the 7% hurdle.

Exhibit 9-4: Non-Stop Alternatives (Stations only at CLE-CHI)

OPTION	$ Bill CapCost	3% OR	3% BCR	7% BCR	3% NPV	7% NPV
CLE-CHI Straight Line No Stops	$20.8	1.70	0.87	0.52	($2,879)	($9,079)
CLE-CHI Hybrid No Stops	$16.4	1.62	1.05	0.63	$854	($5,650)
CLE-CHI Toll Road No Stops	$16.9	1.59	1.01	0.61	$199	($6,169)

	------ All in Millions for 2030 ------						
OPTION	Riders	Revenue	Pass-Miles	Frt-Rev	Average Fare per Rider	Average Miles per Rider	Average ¢/Mile
CLE-CHI Straight Line No Stops	3.03	$291	944	$115	$96	312	31
CLE-CHI Hybrid No Stops	3.00	$289	936	$114	$96	312	31
CLE-CHI Toll Road No Stops	2.98	$287	930	$114	$96	312	31

Exhibit 9-5: Adding Service to Intermediates

OPTION	$ Bill CapCost	3% OR	3% BCR	7% BCR	3% NPV	7% NPV
CLE-CHI Hybrid w/TOL	$16.6	1.88	1.30	0.79	$5,816	($3,359)
CLE-CHI Toll Road w/TOL+SBN	$17.4	2.03	1.49	0.91	$10,210	($1,509)

	------ All in Millions for 2030 ------						
OPTION	Riders	Revenue	Pass-Miles	Frt-Rev	Average Fare per Rider	Average Miles per Rider	Average ¢/Mile
CLE-CHI Hybrid w/TOL	5.02	$375	1,202	$148	$75	240	31
CLE-CHI Toll Road w/TOL+SBN	6.70	$460	1,494	$179	$69	223	31

Exhibit 9-6: Pittsburgh Extension via Cranberry

OPTION	$ Bill CapCost	3% OR	3% BCR	7% BCR	3% NPV	7% NPV
YNG-CLE-CHI Hybrid	$21.4	1.88	1.23	0.74	$5,616	($5,218)
YNG-CLE-CHI Toll Road	$22.1	2.02	1.42	0.86	$10,968	($2,901)
PIT-CLE-CHI Hybrid	$25.2	2.37	1.85	1.15	$26,889	$3,647
PIT-CLE-CHI Toll Road	$25.9	2.58	2.15	1.34	$38,197	$8,883

	------ All in Millions for 2030 ------						
OPTION	Riders	Revenue	Pass-Miles	Frt-Rev	Average Fare per Rider	Average Miles per Rider	Average ¢/Mile
YNG-CLE-CHI Hybrid	6.02	$450	1,442	$176	$75	240	31
YNG-CLE-CHI Toll Road	7.78	$552	1,792	$211	$71	230	31
PIT-CLE-CHI Hybrid	10.69	$835	2,693	$382	$78	252	31
PIT-CLE-CHI Toll Road	13.74	$1,043	3,411	$432	$76	248	31

9.4.3 Pittsburgh Extension via Cranberry

As shown in Exhibit 9-7, Youngstown would add about 1 million riders and Pittsburgh would add 6 million more riders. As a result, extending service from Cleveland east to Pittsburgh would double the ridership and increase freight revenue by 250%, as compared to a corridor that only ends in Cleveland.

Further, it can be seen in Exhibit 9-5 that options that extend east to Youngstown have a lower BCR than do options that end in Cleveland. While some of the extensions to Youngstown have a positive BCR at 3%, all of them fail at 7%. This suggests that Youngstown is not a strong enough market to anchor a Hyperloop route. This result suggests that a Hyperloop corridor needs to go all the way to Pittsburgh to support the economic viability of an extension east from Cleveland.

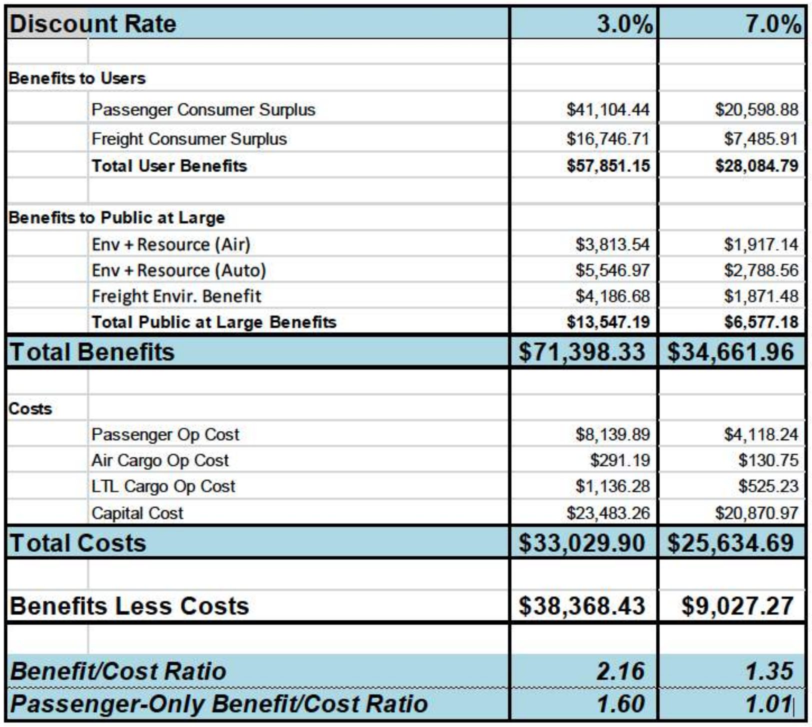
For a Pittsburgh-Cleveland-Chicago option via Cranberry this would result in an average requirement for 530 (50 person) passenger capsules per day each way plus 120 freight capsules by 2030. These are divided between the CHI-CLE and CLE-PBG legs. Assuming each leg gets 2/3 loading this is (530+120)*0.66 = 433 capsules per day. This would utilize only 433/480 = 88% of the guideway capacity during the daytime hours.

Because of its excellent guideway capacity utilization, this either the Toll Road or Hybrid option, if extended to Pittsburgh would produce an approximate 2.5 Operating Ratio and it would have a BCR > 1.0 at both 3% and 7% interest rate. The Toll Road option performs better than does the Hybrid because of the extra station stop in South Bend. In addition, at a 3% ROI the NPV of Passenger, Freight and Real Estate revenues exceeds the Operating + Capital cost NPV. This means it is likely that a PPP could finance most of the capital cost for a Chicago-Pittsburgh system. Detailed results for the Pittsburgh-Cleveland-Chicago toll road option are given in Exhibit 9-6.

- At a real interest rate of 3%, which approximates the government's cost for borrowing money; the Hyperloop project generates a 2.16 Benefit Cost ratio via Cranberry and a 2.20 Benefit Cost ratio via Pittsburgh Airport.
- At the much higher 7.0 percent interest rate, which is really a capital rationing rate, the project via Cranberry still produces a healthy 1.35 Benefit Cost and 1.38 via Pittsburgh airport. This reflects a heavier weighting of the up-front capital in terms of the timing of expenditures, but the result is still producing a positive (>1.0) result which shows that the project is still justified even at the very high real interest rate of 7.0 percent.
- The project generates strongly positive Operating Ratios exceeding 4.0 for combined passenger and freight; and passenger-only Operating Ratios exceeding 2.5. This means that a Hyperloop would not need an operating subsidy since it could easily cover its operating cost out of its own farebox revenues.
- Freight can make a strong contribution to the economics of Hyperloop by increasing the project's revenue earning capability. This means that the private sector could contribute a substantial share of the project's capital cost. For example, at 3% interest, the project revenue NPV of more than $40 Billion exceeds the total cost NPV of $33+ Billion by a considerable margin. This means that it may even be possible for the project to be entirely privately financed provided it can access the necessary capital at favorable interest rates.

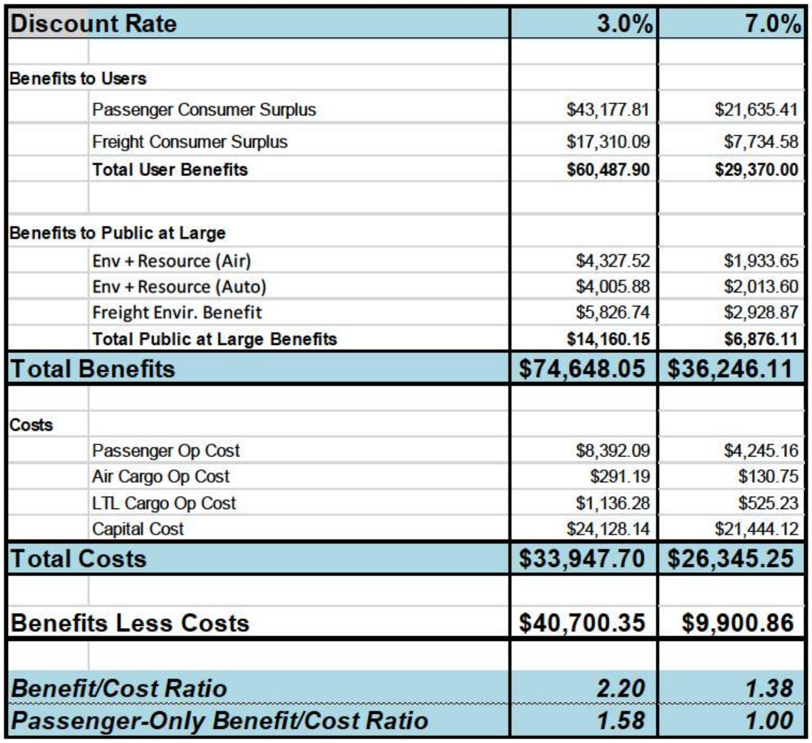
Exhibit 9-7: Great Lakes Hyperloop – Cost Benefit Results for Cleveland-Chicago Toll Road with:

(a) Pittsburgh via Cranberry



Discount Rate		3.0%	7.0%
Benefits to Users			
	Passenger Consumer Surplus	$41,104.44	$20,598.88
	Freight Consumer Surplus	$16,746.71	$7,485.91
	Total User Benefits	**$57,851.15**	**$28,084.79**
Benefits to Public at Large			
	Env + Resource (Air)	$3,813.54	$1,917.14
	Env + Resource (Auto)	$5,546.97	$2,788.56
	Freight Envir. Benefit	$4,186.68	$1,871.48
	Total Public at Large Benefits	**$13,547.19**	**$6,577.18**
Total Benefits		**$71,398.33**	**$34,661.96**
Costs			
	Passenger Op Cost	$8,139.89	$4,118.24
	Air Cargo Op Cost	$291.19	$130.75
	LTL Cargo Op Cost	$1,136.28	$525.23
	Capital Cost	$23,483.26	$20,870.97
Total Costs		**$33,029.90**	**$25,634.69**
Benefits Less Costs		**$38,368.43**	**$9,027.27**
Benefit/Cost Ratio		***2.16***	***1.35***
Passenger-Only Benefit/Cost Ratio		***1.60***	***1.01***

(b) Pittsburgh via Airport



Discount Rate		3.0%	7.0%
Benefits to Users			
	Passenger Consumer Surplus	$43,177.81	$21,635.41
	Freight Consumer Surplus	$17,310.09	$7,734.58
	Total User Benefits	**$60,487.90**	**$29,370.00**
Benefits to Public at Large			
	Env + Resource (Air)	$4,327.52	$1,933.65
	Env + Resource (Auto)	$4,005.88	$2,013.60
	Freight Envir. Benefit	$5,826.74	$2,928.87
	Total Public at Large Benefits	**$14,160.15**	**$6,876.11**
Total Benefits		**$74,648.05**	**$36,246.11**
Costs			
	Passenger Op Cost	$8,392.09	$4,245.16
	Air Cargo Op Cost	$291.19	$130.75
	LTL Cargo Op Cost	$1,136.28	$525.23
	Capital Cost	$24,128.14	$21,444.12
Total Costs		**$33,947.70**	**$26,345.25**
Benefits Less Costs		**$40,700.35**	**$9,900.86**
Benefit/Cost Ratio		***2.20***	***1.38***
Passenger-Only Benefit/Cost Ratio		***1.58***	***1.00***

9.5 Private Public Partnership Potential

The financial and economic results show a strong case for Public Private Partnership (PPP) for the Hyperloop project in the Great Lakes Hyperloop corridor. The basic components for such a partnership are –

- **For the Private side** – a strong financial performance giving a good return on investment. This is buoyed by the ability to move air, LTL and express freight and to develop Transit Oriented Development around stations and terminals. These are both areas Wall Street have long financed by using bonds. Equally, the flatness of the fare revenue yield structure used for the passenger ridership suggests there is an ability to absorb a Wall Street conservative market down in passenger ridership revenues (to reduce risk) that is typical for high-speed ground transportation systems.
- **For the Public side** – significant economic benefits appearing on both the demand and supplyside of the economy. The Cost Benefit Ratio and Net Present Values suggest a very powerful boost to the economy, and the kind of impact on GDP that the development of the national Interstate system had as it spurred manufacturing industry. Hyperloop will spur the New Economy service industries of finance, software, and logistics with a great increase in accessibility and the integration of mega regions. Hyperloop will provide an ability to link the East and West Coasts to the Midwest, Texas, and the South, with speeds comparable to air and an ability to link medium and large towns and cities across the USA.

In addition to the benefits listed above, the Public Sector will receive an improved cash flow bonus from the building of the system in terms of transfer payments from the developed corridors. This benefit will be assessed in the next section and will consist of increased tax revenues flow from the growth in employment, income, property development, and increased commercial sales of goods and services.

Given the advantages to both sides the collaboration of the Public and Private Sectors can be realized in a number of ways. This can include –

- BOOT- F Agreements: Build, Own, Operate, Transfer and Finance (e.g., Channel Tunnel)
- BOT: Build, Own and Transfer (e.g., Sidney Harbor Tunnel)
- BOO: Build, Own and Operate
- BDFO: Build, Design, Finance and Operate
- BLT: Build, Lease, Transfer
- Operating and Management Contracts
- Leasing

The results suggest financing by both the Public and Private sectors, with for example government reassuring Wall Street by providing Senior Debt or Guarantees of Passenger Revenues. Key steps in creating a PPP include –

- Developing the Political Framework
- Right Legal Framework
- Public Acceptance

- Competitive and Proven Technology
- Financial Security and Stability in Cash Flows and Funding Plans

9.6 Economic Rent/Community Benefits

In order to estimate the economic impact of the Great Lakes Hyperloop, it is important to understand the character of the different economic benefits

Benefits will arise from the development and the presence of the Great Lakes Hyperloop. The impact of these benefits will be significant both at a firm and household level (see Exhibit 8-5 below). However, it is important to understand that the sets of benefits quantified in this report, assume equilibrium in the economy. In order for the economy to be in equilibrium, the Supplyside Benefits must equal Demandside Benefits. Supplyside and Demandside benefits should not be added together in the assessment of the full benefits of the project, as they are merely two different measurements of the same benefits.[29]

9.6.1 The Character of the Overall Economy

The model of the economy[30] shows that an economy is circular in character, with two equal sides (Exhibit 9-8). On one side of the economy is the consumer side – the market for goods and services – in which consumers buy goods and services by spending the income earned by working for a commercial enterprise. If a transportation investment improves travel times and costs for individuals, it increases consumer surplus. An analysis of the impact of a transportation investment on the market for goods and services quantifies the level of Consumer Surplus generated by a project, by showing how much time, money and resources individuals save.

The notion that a transportation project will be worthwhile if travel is made more cost effective is based on the idea that not only the cost, but also the travel time of a trip has value. Academic and empirical research has shown that this concept holds true for business, commuter and recreational travelers as well. Considerable research has been carried out to both identify the theoretical justification for value of travel time and to quantify its value.

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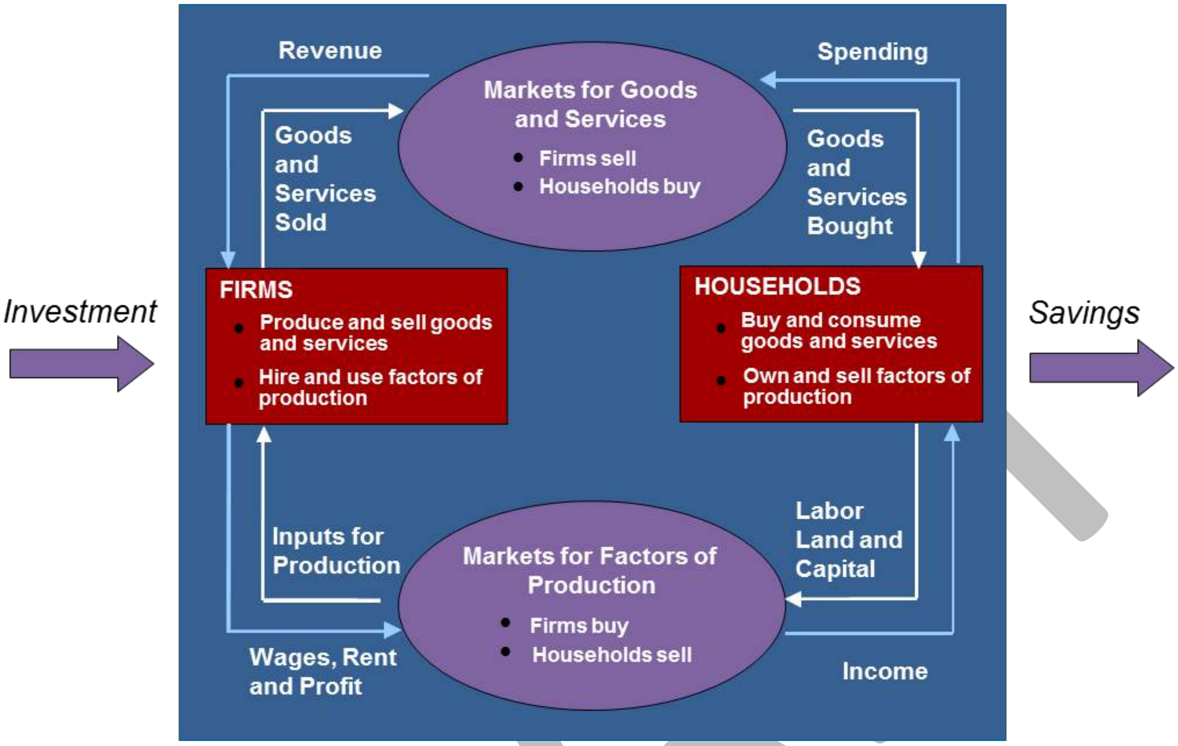
[29] See: Mishan, E. 'Cost Benefit Analysis,' New York, NY: Praeger Publishers, 1976.

[30]

Exhibit 9-8: Simple Model of the Economy[31]



On the other side of the economy is the market for factors of production. Most importantly, it is the market for land, labor and capital, which individuals provide to firms in exchange for wages, rent and profit. From the perspective of policy makers and the local community, this side of the economy is very interesting as it shows how investment in a new transportation infrastructure changes the productivity of the economy by creating new business opportunities; and therefore, increases jobs, income and wealth.

One of the most important aspects of the circular economy model is that it shows that any project has two impacts, one in the consumer market – the benefits to travelers; the second, in the factor markets or Supplyside of the economy[32] – which identifies benefit to the community in terms of improved welfare due to increases in jobs, income and wealth. The supplyside benefits can be quantified as the increase in Economic Rent. This is shown in Exhibit 9-9.

For the economy to reach equilibrium, both sets of benefits must be realized. As such, the benefits of a project are realized twice, once on the Demandside and once on the Supplyside. As a result, there are two ways to measure the productivity benefits of a transportation project; and theoretically, both measurements must equal each other. This is a very useful property since in any specific analysis one measure can be used to check the other, at least at the aggregate level. This is very helpful and provides a check on the reasonableness of the estimates of project benefits.

However, in assessing the benefits of a transportation project, it is important not to double-count the benefits by adding Supplyside and Demandside benefits together. It must be recognized that these two sets of benefits are simply two different ways of viewing the same benefit. The two markets are both reflections of each other and

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[31] See Samuelson, P. & Nordhaus, W. Economics. 14th Edition. New York: McGraw-Hill. 1992.

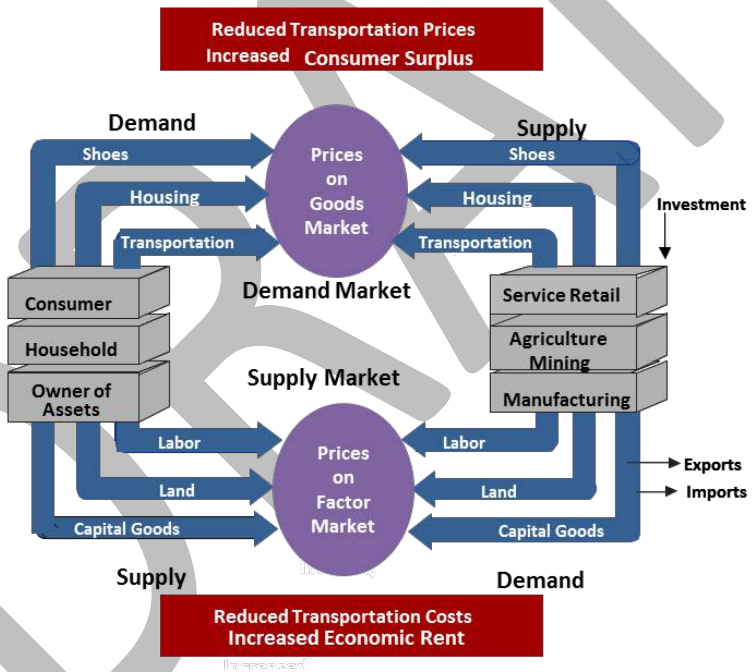
[32] See: Mishan, E. 'Cost Benefit Analysis,' New York, NY: Praeger Publishers, 1976.

measure the same thing. For example, if both sets of benefits equal $50 million, then the total benefit is only $50 million as expressed in two different ways: travelers get $50 million of travel benefits and the community gets $50 million in jobs, income, and increased profits. As a ripple effect (or transfer payment), the economy also gets an expanded tax base and temporary construction jobs.

Therefore, if a given transportation project is implemented, equivalent productivity benefits will be seen in both the consumer market for goods and services (as the economy benefits from lower travel times and costs); as well as in the Supplyside factor markets. In the Supplyside side market, improved travel efficiency is reflected in more jobs, income and profit. Therefore, for a given transportation investment, the same benefit occurs on both sides of the economy. In the consumer markets, users enjoy lower travel costs and faster travel times. On the Supplyside of the economy, the factor markets take advantage of the greater efficiency in transportation. As a result, both sides of the economy move to a new level of productivity in which both sides of the economy are balanced in equilibrium.

Improved efficiency will generate Supplyside spending and productivity benefits that have a very real impact on the performance of the local economy. The method that develops estimates of productivity jobs and wealth creation is an Economic Impact Analysis. It measures how the performance of a new transportation investment raises the efficiency of the economy. This efficiency improvement creates jobs and income and raises local property values to reflect the improved desirability of living or working in the area.

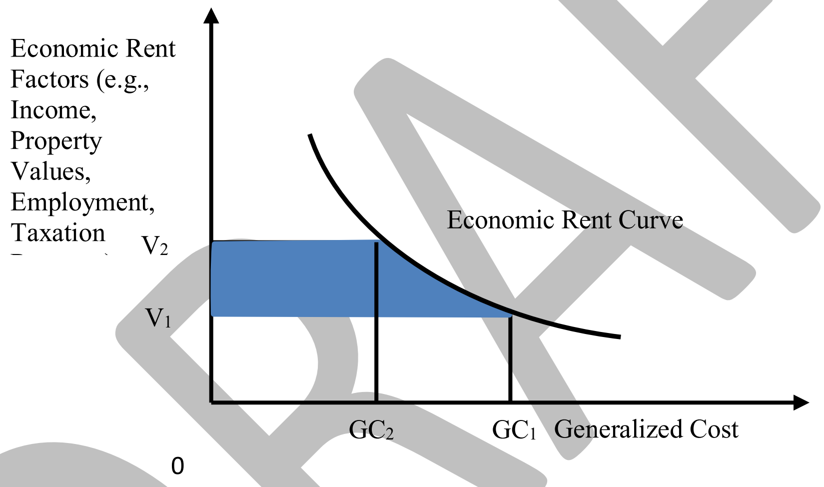
Exhibit 9-9: Relation between Consumer Surplus and Economic Rent in the Economy



9.6.2 Assessing Supplyside Benefits

The Economic Rent theory builds from the findings of Urban Economics and The Economics of Location that support Central Place Theory[33]. Central Place Theory argues that in normal circumstances, places that are closer to the "center" have a higher value or economic rent. This can be expressed in economic terms; particularly jobs, income, and property value. There is a relationship between economic rent factors (as represented by employment, income, and property value) and impedance to travel to market centers (as measured by generalized cost). As a result, lower generalized costs associated with a transport system investment lead to greater transportation efficiencies and increased accessibility. This, in turn, results in lower business costs/higher productivity and, consequently, in an increase in economic rent. This is represented by moving from point V1 to point V2 in Exhibit 9-10, as a result of the improved accessibility as measured by moving from GC1 to GC2.

Exhibit 9-10: Economic Rent Illustration



It should be noted that the shape of the economic rent curve reflects the responsiveness (elasticity) of the economy to an improvement in accessibility. Large cities typically have very large economic rent activity (represented by a steep Economic Rent Curve), which indicates that a project improving transportation accessibility will have a significant economic impact; smaller communities have less economic rent activity (less steep curves), and rural areas have very flat curves that indicate lower economic responsiveness. Similarly, depressed areas will experience flatter curves than better off areas. This is due to factors not directly related to transportation, such as level of education, population structure and industrial structure. A significantly improved transportation provision may bring a useful contribution to alleviating the problems faced by disadvantaged areas, but will not by itself solve the economic issues and problems that these areas face. See Exhibit 9-11.

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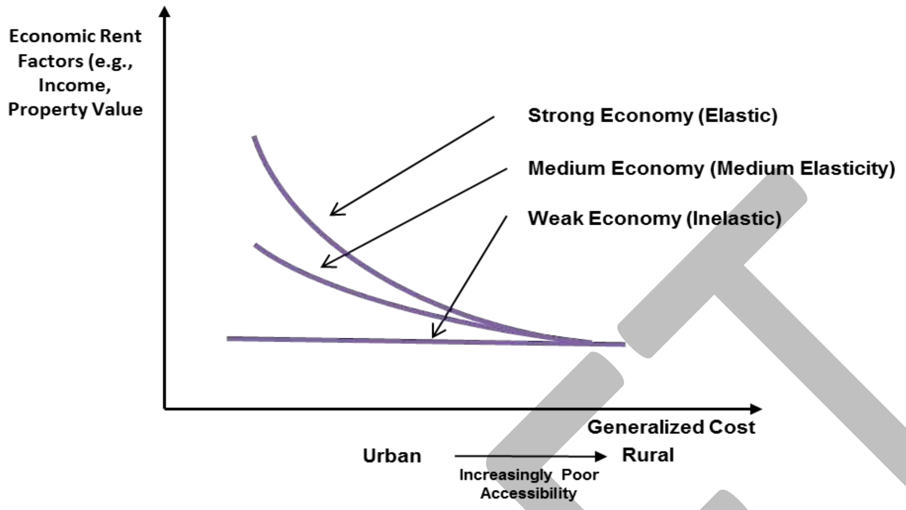
[33] Metcalf, A.E. 'Economic Rent: A New Dimension in the Economic Evaluation Process', Transportation Research Board, 71st Annual Meeting, January 12-16, Washington, DC, 1992.

Exhibit 9-11: Representation of Different Economic Rent Curves by Strength of Economy



Finally, the strength of the relationship between generalized cost and economic factors is established by calculating the relationship between economic rent factors and generalized cost weighted by the amount of trips completed for the particular region of study. This ensures that when calculating the Supplyside effect of a transportation improvement, real gains in accessibility that benefit a large number of users, produce greater Supplyside benefits than projects that provide real accessibility gains for a small number of individuals. The mathematical expression of the Economic Rent Curve is therefore:

$SE_i = \text{ß}_0 \, GC_i$

Where:

SE_i - Economic rent factors – i.e., socioeconomic measures, such as: employment, income, property value of zone i;

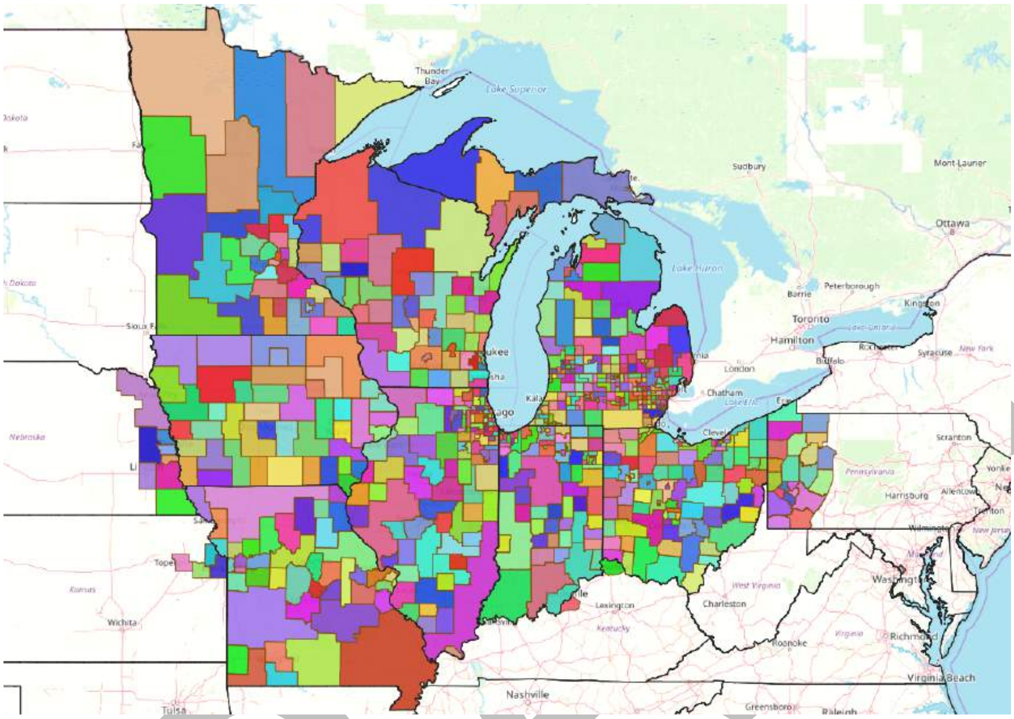
GC_i - Weighted generalized cost of auto travel for all purposes from (to) zone i to (from) other zones in the study area;

ß_o - Calibration parameters.

9.6.3 Data Sources and Study Database

For the economic impact study, zones developed in the Hyperloop Corridor Study were adopted from earlier Chapters of this report, as shown in Exhibit 9-12.

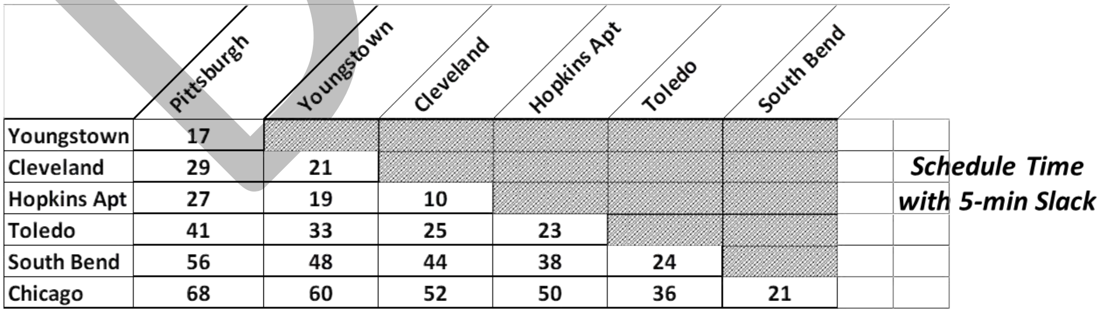
Exhibit 9-12: Zonal System used for the Purpose of the Study



In order to estimate the economic impact, base year 2018 socioeconomic database established in ridership and revenue study were used for the supplyside model calibration, and socioeconomic forecasts were used in calculating supplyside benefits in the 30-year period from 2025 to 2050.

This information enabled TEMS to use the network of Toll Road Option Hyperloop service shown in Exhibit 9-13 to establish transportation service improvements for the zones in the corridor, and to calculate both the current and future generalized costs.

Exhibit 9-13: Toll Road Option Hyperloop Running Times



	Pittsburgh	Youngstown	Cleveland	Hopkins Apt	Toledo	South Bend
Youngstown	17					
Cleveland	29	21				
Hopkins Apt	27	19	10			
Toledo	41	33	25	23		
South Bend	56	48	44	38	24	
Chicago	68	60	52	50	36	21

Schedule Time with 5-min Slack

9.6.4 Supplyside Analysis: Deriving Economic Rent Elasticities

Economic Rent theory proposes that for a transportation project to have value there will be a strong relationship between socioeconomic variables and accessibility. As such, the relationship between accessibility and income, employment, and property density in the Cleveland Hyperloop Corridor was calculated through regression analysis. This analysis established the level of sensitivity of the region's economy to transportation improvements. Exhibits 9-14, 9-15, and 9-16 show the relationship established between accessibility and employment, income, and real property value, along with the statistical measures indicating the strength of the relationship found.

As can be seen in the relationship exhibits, the relationship between accessibility and socioeconomic characteristics is a linear relationship of the following form:

$$\ln (SE_i) = \beta o + \beta 1 \ln (GC_i) \qquad \textbf{Equation 1}$$

Where:

SE_i - Economic rent factor (socioeconomic variable) of zone i;

GC_i - Weighted generalized cost of travel for all purposes from (to) zone i to (from) other zones in the zone system;

βo and $\beta 1$ - Regression coefficients.

Exhibit 9-14: Relation between Accessibility and Employment in the Hyperloop Corridor

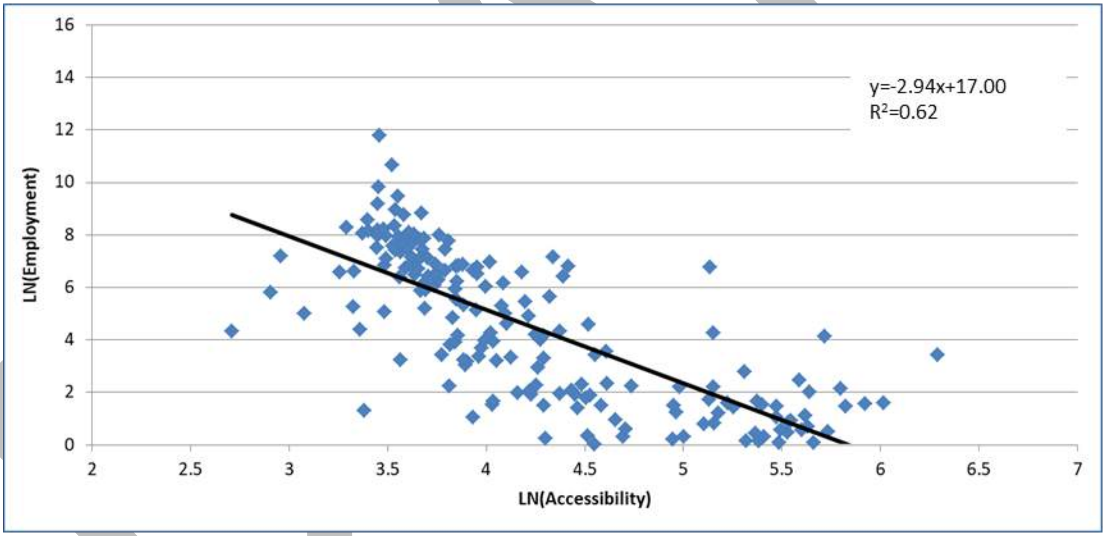


Exhibit 9-15: Relation between Accessibility and Income in the Hyperloop Corridor

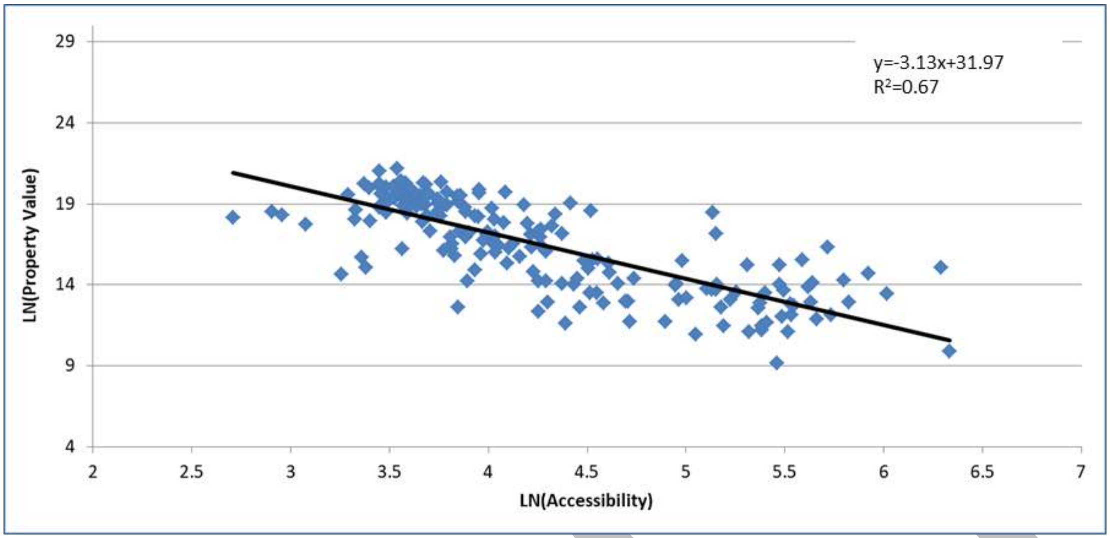
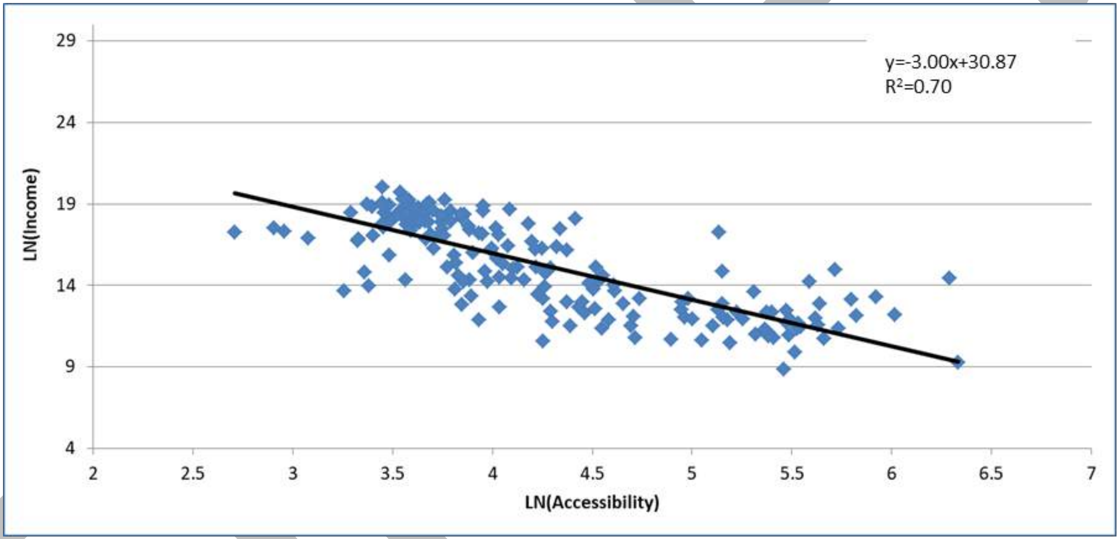


Exhibit 9-16: Relation between Accessibility and Real Property Values in the Hyperloop Corridor



The value of the coefficients of determination (R^2) shows how much the dependent variable (e.g. employment) is influenced by the predictor variable (accessibility). In other words, the coefficient of determination measures how well the model explains the variability in the dependent variable. R^2 therefore illustrates the strength of the relationship between the dependent and predictor variables.

Student's t statistics were calculated for the two regression coefficients - β0 (the intercept) and β1 (the slope) indicate the significance of the regression coefficients. A t-statistics above the value of two in absolute terms is generally accepted as statistically significant.

It can be seen that for the current study, the calibration was successful and regression coefficients in each equation were shown to be significant. (See Exhibits 9-13, 9-14, and 9-15). This shows that the economic rent profiles are well developed for the Cleveland Hyperloop Corridor. Each equation has highly significant 't' values and coefficients of determination (R^2). This reflects the strength of the relationship and, given the fact that there is a strong basis for the relationship, shows firstly, that the socioeconomic variables selected provide a reasonable representation of economic rent; and, secondly, that generalized cost is an effective measure of market accessibility. Exhibit 9-17 shows the detailed calibration results for employment, income, and property values.

Exhibit 9-17: Detailed Calibration Results

Economic Rent Factor	Intercept (βo)	T-statistics for βo	Slope (β1)	T-statistics for β1	Coefficient of Determination – 'R square' (R^2)
Employment	17.00	24.29	-2.94	-18.23	0.62
Income	31.97	41.70	-3.13	-19.04	0.67
Real Property Value	30.87	-18.84	-3.00	-18.59	0.70

The impact on the socioeconomic indicators gathered for the current study, with regard to the improvement in accessibility provided by the new Hyperloop system, is calculated according to the elasticities (i.e. the sensitivity of the socioeconomic parameters to accessibility) established through the differentiation of the economic rent function in equation (1) with respect to generalized cost. The result of such differentiation is present in Equation 2. It is easy to see that slope β_1E in the regression equation represent economic rent elasticities.

$$\Delta SE_I = \frac{\partial SE_I}{SE_I} = \beta_1^E \frac{\partial GC_I}{GC_I}$$ **Equation 2**

The resulting elasticities were then applied to each zone pair according to the specific generalized cost improvement calculated for each zone for each phase of the project. This allows for the effect of Hyperloop to be calculated from a Supplyside perspective.

The resulting effect on the socioeconomic parameters are presented below. The results are estimated for each zone, and for the purpose of reporting, socioeconomic benefits for each station hinterland will be shown in the following session.

9.6.5 Direct Socioeconomic Benefits Results

Direct socioeconomic benefits include employment benefits, income benefits, and real property value benefits. Employment benefits are derived from the Hyperloop Corridor transportation service improvement. These are productivity jobs and not temporary construction jobs associated with building the project. Income benefits are derived from the increased attractiveness of the region due to the accessibility improvement. Income benefits result from both the increase in the number of households in the corridor and the increase in the average household income per household. Real property value benefits result from the increase of the number of properties in the region as well as increase in the average value of commercial and residential buildings.

9.6.5.1 Employment Growth Estimates

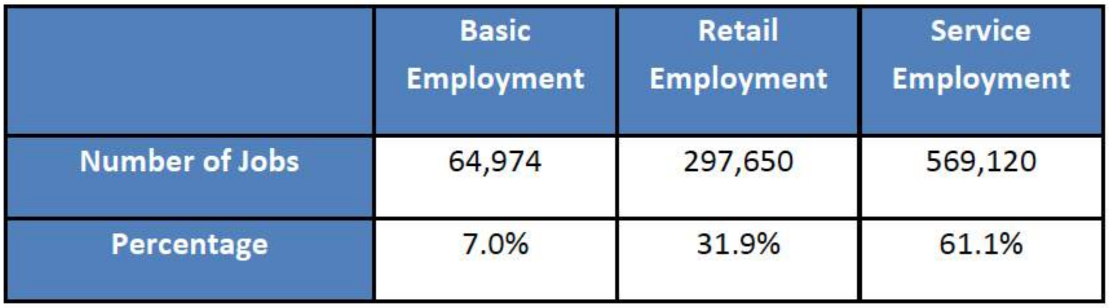
Exhibit 9-18 shows that the total employment growth in man years from 2025 to 2050 in the Hyperloop Corridor will be over 931 thousand. This implies that over the 25-year economic life of the project, that nearly 40,000 additional job positions will be created permanently and in each one of the 25 years. Chicago will have more than 425 thousand person years employment increase, Cleveland (including Hopkins Airport) will have over 190 thousand person years of employment growth, Pittsburgh will have 146 thousand more person years of employment. Other urban areas in the corridor will have 168 thousand person years of employment increase.

Exhibit 9-18: Employment Improvement by Station Coverage Area

Station Name	Employment Improvement (man year) 2025~2050
Chicago, IL	425,628
South Bend, IN	67,755
Toledo, OH	64,306
Hopkins Airport, OH	37,928
Cleveland, OH	153,169
Youngstown, OH	36,592
Pittsburgh, PA	146,367
Total	**931,745**

Exhibits 9-19, 9-20, and 9-21 show the corridor employment improvement by sectors, namely, basic employment, retail employment, and service employment. It can be seen that service employment accounts for more than 60 percent of total employment improvement, while retail employment has 32 percent of total employment improvement and basic employment accounts for seven percent.

Exhibit 9-19: Employment Improvement by Sector



	Basic Employment	Retail Employment	Service Employment
Number of Jobs	64,974	297,650	569,120
Percentage	7.0%	31.9%	61.1%

Exhibit 9-20: Employment Improvement by Sector – Number of Jobs

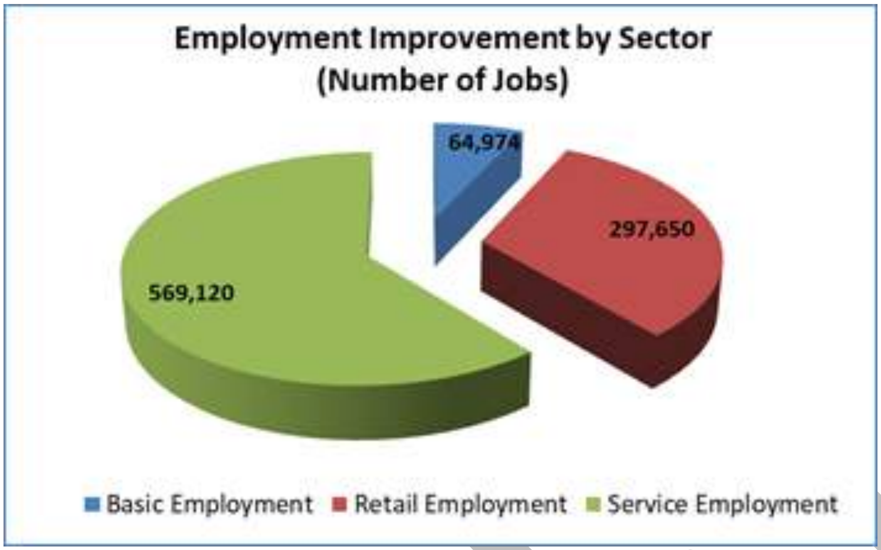
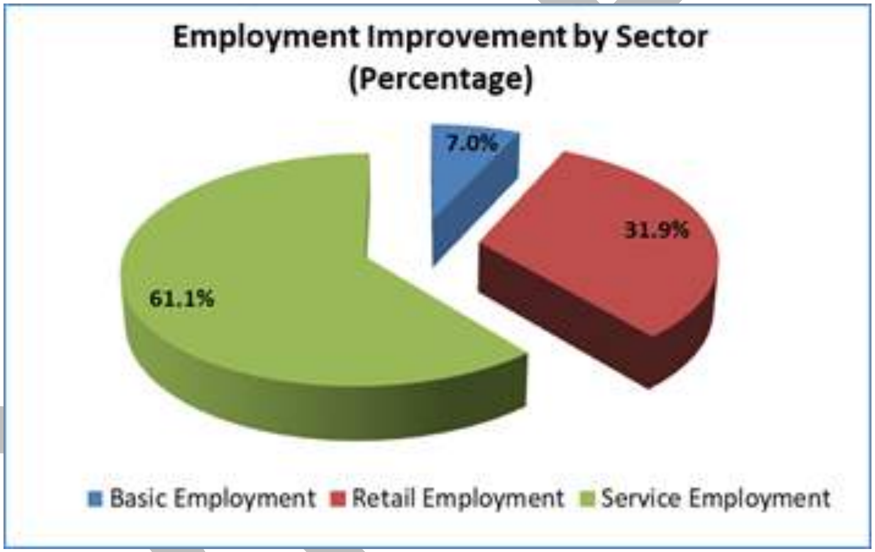


Exhibit 9-21: Employment Improvement by Sector – Percentage of Jobs



9.6.5.2 Personal Income Growth Estimates

The personal income growth is shown in Exhibit 9-22. It can be seen that the total income growth in the corridor will be more $45.6 billion from 2025 to 2050. Chicago, Cleveland, and Pittsburgh will have $21.5 billion, $9.8 billion, and $7.6 billion income increase during this 25-year period. Other areas in the corridor will have nearly $8.6 billion income growth.

Exhibit 9-22: Personal Income Improvement by Station Coverage Area

Station Name	Income Improvement 2025~2050 (million $)
Chicago, IL	21,555
South Bend, IN	3,503
Toledo, OH	3,189
Hopkins Airport, OH	1,946
Cleveland, OH	7,890
Youngstown, OH	1,888
Pittsburgh, PA	7,605
Total	**47,577**

9.6.5.3 Real Property Value Growth Estimates

Exhibit 9-23 shows the real property value growth in the corridor from 2025 to 2050. The real property value in the corridor will also increase as result of the Hyperloop service. The total amount of real property value increase from 2025 to 2050 will be $75 billion. Chicago, Cleveland, and Pittsburgh will have $34 billion, $15.3 billion, and $11.9 billion property value increase from 2025 to 2050. Other areas in the corridor will have more than $13.6 billion property value increase.

Exhibit 9-23: Property Value Improvement by Station Coverage Area

Station Name	Property Value Improvement 2025~2050 (million $)
Chicago, IL	34,045
South Bend, IN	5,457
Toledo, OH	5,169
Hopkins Airport, OH	3,037
Cleveland, OH	12,257
Youngstown, OH	2,994
Pittsburgh, PA	11,882
Total	**74,842**

9.6.6 Transfer Payments (Tax Benefits)

Transfer payments play an exceptional role in the overall project evaluation. This is not because they are a real economic benefit, but because cash flow to Government directly affects the Government's ability to afford the cost of projects. The tax benefits include real property tax increase as result of real property value appreciation, the federal and local income taxes will also benefit as result of personal income increase in the corridor. The rates used reflect 2018 tax rates.

9.6.6.1 Real Property Tax Growth Estimates

Exhibit 9-24 shows the real property tax increase in the Hyperloop Corridor from 2025 to 2050. The real property tax in the corridor will increase as result of the increased real property value in the corridor. The total amount of real property tax increase from 2025 to 2050 will be $1.27 billion. Chicago will have 570 million increase in real property tax payments due to improved assessments and higher real estate values. Cleveland and Pittsburgh will similarly have $268 and $206 million increases in real property tax collections from 2025 to 2050. Other urban areas in the corridor will have nearly $230 million increases in real property tax revenues.

Exhibit 9-24: Property Tax Improvement by Station Coverage Area

Station Name	Property Tax Improvement 2025~2050 (million $)
Chicago, IL	570
South Bend, IN	95
Toledo, OH	85
Hopkins Airport, OH	52
Cleveland, OH	214
Youngstown, OH	50
Pittsburgh, PA	206
Total	**1,273**

9.6.6.2 Federal Income Tax Growth Estimates

The federal income tax growth as result of income growth in the Hyperloop Corridor is shown in Exhibit 9-25. It can be seen that the total federal income growth in the corridor will be over $9.4 billion from 2025 to 2050. Chicago, Cleveland, and Pittsburgh will have $4.22 billion, $1.96 billion, and $1.5billion federal income tax increase from 2025 to 2050. Other areas in the corridor will have more than $1.7 billion increase of federal income tax.

Exhibit 9-25: Federal Tax Improvement by Station Coverage Area

Station Name	Federal Tax Improvement 2025~2050 (million $)
Chicago, IL	4,225
South Bend, IN	682
Toledo, OH	650
Hopkins Airport, OH	392
Cleveland, OH	1,575
Youngstown, OH	373
Pittsburgh, PA	1,505
Total	**9,401**

9.6.6.3 Local Tax Growth Estimates

The local income tax growth as result of income growth in the Hyperloop Corridor is shown in Exhibit 9-26. It can be seen that the total federal income growth in the corridor will be $2.02 billion from 2025 to 2050. Chicago, Cleveland, and Pittsburgh will have $919 million, $418 million, and $319 million federal income tax increase from 2025 to 2050. Other areas in the corridor will have more than $365 million increase of local income tax.

Exhibit 9-26: Local Tax Improvement by Station Coverage Area

Station Name	Local Tax Improvement 2025~2050 (million $)
Chicago, IL	919
South Bend, IN	150
Toledo, OH	136
Hopkins Airport, OH	82
Cleveland, OH	336
Youngstown, OH	79
Pittsburgh, PA	319
Total	**2,021**

9.6.7 Conclusions

Below is a summary of each set of benefits calculated for the Hyperloop project. As seen in the analysis, the proposed Hyperloop project will not only generate financial and demandside economic benefits but will provide a strong stimulus the economy of the corridor. Supplyside benefits are the estimated benefits to business and the economy due to the increase in accessibility provided by improvements in transport infrastructure. It is based on the relationship (the elasticity) that the economy exhibits today to transportation accessibility (i.e., sensitivity to improved accessibility). Given the circular nature of the economy, Supplyside benefits under economic theory are equal to the Demandside benefits due to the integrated nature of the economy. The project will create long-term well-paid service employment due to improved productivity. Furthermore, it will benefit the general population through higher incomes and higher real property values. Federal and local government will be able to recoup 50 to 55 percent of the capital cost contributions of their investment ($12.6 Billion) in the project through an expanded tax base. Exhibit 9-27 shows the overall socioeconomic and transfer payment benefits of the Hyperloop Corridor for the 25-year period from 2025 to 2050.

Exhibit 9-27: Socioeconomic and Transfer Payments Improvements Summary

Economic Supply Side Items	Economic Supply Side Improvements
Direct Socioeconomic Benefits	
Employment (2025~2050 man year)	931,745
Income (2025~2050, million $)	47,577
Property Value (2025~2050, million $)	74,842
Transfer Payments (Tax Benefits)	
Local Income Tax (2025~2050, million $)	2,021
Federal Income Tax (2025~2050, million $)	9,401
Property Tax (2025~2050, million $)	1,273
Total Tax Payments	**12.7 Billion**

Estimates over the 25-year life of the project are:

- Long-term productivity employment will rise by 931,745 person years. The jobs will be created in the business services, logistics, maintenance, health care and retail sectors.
- $47.57 Billion increase in personal income over 25 years throughout the Corridor. This is nearly two times the capital cost of the project.
- Property Values are estimated to rise by $74.84 Billion. This is three times the capital cost of the project.

The economic impacts of the project in terms of transfer payments are:

- $9.4 billion new federal tax over 25 years will be generated.
- $2.02 billion new local tax over 25 years will be generated.
- $1.27 billion in property tax will be collected at the local level.

This represents 50-55 percent of the capital cost of the project.

Chapter 10

Public Outreach

Summary

The Northeast Ohio Areawide Coordinating Agency (NOACA) is the federally designated metropolitan planning organization (MPO) for Cuyahoga, Geauga, Lake, Lorain and Medina counties. NOACA performs planning for highways, bridges, public transit, bikeways and pedestrian facilities. The agency also conducts transportation-related air quality planning and functions as the areawide water quality planning agency. NOACA's 45-member Board of Directors, consisting of elected and appointed public officials from the five-county region, who determines how federal transportation dollars are spent in Northeast Ohio. The agency works closely with local communities, county engineers, transit agencies, the Ohio Department of Transportation (ODOT), and other stakeholders on project planning, development and funding in a public forum. The agency takes a broad and balanced view of the region's multimodal transportation system and seeks to preserve and improve the system throughout the entire metropolitan area.

10.1 NOACA Vision Statement

Through its vision statement, NOACA will STRENGTHEN regional cohesion, PRESERVE existing infrastructure, and BUILD a sustainable multimodal transportation system to SUPPORT economic development and ENHANCE the quality of life in Northeast Ohio.

A key strategy identified to support the fulfillment of NOACA's vision statement is to further develop and leverage strong relationships with community, economic development and business partners. NOACA accomplishes this in accordance with federal regulations through such methods as:

- Providing information and education
- Using visualization techniques
- Giving timely public notice
- Using a variety of in-person and online opportunities to participate
- Enabling public access to key decisions
- Considering significant comments on its planning documents

10.2 Public Participation Goals

NOACA is committed to informing and educating the public about its planning work, as well as providing opportunities for members of the public to be involved and participate in developing and implementing that work. To do that, NOACA:

- Provides timely information about planning issues and processes to the public.
- Fosters transparency by providing reasonable public access to technical and policy information used in the development of transportation plans.
- Provides adequate notice of public involvement and planning activities.
- Continually seeks specific ways to engage and consider the needs of all segments of the population.
- Obtains early and continuous public involvement in the transportation planning process.

10.3 Purpose

The purpose of the engagement efforts for the Great Lakes Hyperloop is to inform identified stakeholders and the general public about Hyperloop in the Cleveland, OH – Chicago, IL – Pittsburgh, PA corridor, and the development and outcomes of the Great Lakes Hyperloop Feasibility Study. The primary intention of the stakeholder engagement activities is to share information about hyperloop technology with defined audiences and obtain feedback to learn about design, technical capacity, land use, environmental impacts, alternative route analysis, proposed station locations, regional connections and economic growth opportunities.

Each region and stakeholder group will have different lenses on this technology and its use and impact. The following approaches were employed:

- Website to store all the information on the Hyperloop technology. This is the focal point for all data and information on Hyperloop and the study.
- Organized Technical Advisory Committees in Cleveland, Chicago and Pittsburgh to ascertain and gain guidance on the project from a local perspective for a system implementation.
- Stakeholder meetings with identified parties that have a focus on local and regional transportation, urban planning, environmental, educational, economic and development growth for the
- Organized public engagement events to introduce Hyperloop technology and gauge audience preferences

10.4 Technical Advisory Committee (TAC)

NOACA has implemented Technical Advisory Committees in Cleveland, Chicago, and Pittsburgh. The Cleveland TAC membership includes all the northern Ohio MPO's, City of Cleveland, City of Toledo, City of Youngstown, as well as Ohio DOT, Regional FHWA, and Ohio Turnpike and Infrastructure Commission. The Chicago TAC membership includes the Chicago MPO, Chicago Metropolitan Agency for Planning (CMAP), Illinois DOT, Chicago Regional Transit Authority, City of Chicago, Metra, PACE, Illinois Tollway and Amtrak. The Pittsburgh TAC membership includes the Southwestern Planning Commission, City of Pittsburgh, Pittsburgh Airport, RK Mellon Foundation Beaver County, Allegheny County, and the Pennsylvania Turnpike Commission. The TACs have met throughout the project to provide advice and guidance to the project for their region and the entire corridor.

Key Messages: The key messages of the Hyperloop Stakeholder and Public Engagement Plan are:

- Why Hyperloop
- The role that Hyperloop will play in revitalizing regional passenger transportation
- How Hyperloop will stimulate economic development and new land-use
- How Hyperloop will provide service for the air cargo and express parcel freight market
- The way Hyperloop will integrate communities along the corridor
- The new economic opportunities for business and commuting
- How Hyperloop will support the growth of new economy businesses such as financial, software, legal, and logistics industries
- How Hyperloop will change long-term infrastructure needs, change land-use needs and improve environmental, safety and health care benefits
- The benefits of Hyperloop

10.5 Public and Stakeholder Engagement

The NOACA Hyperloop Feasibility Study includes two phases of engagement activities. The first phase includes Stakeholder Engagement, and the second phase of work includes Public Engagement effort.

Stakeholder engagement provided information and messaging targeted to defined stakeholder groups along the Hyperloop corridor to ensure their concerns are considered throughout the study analysis process, particularly in the development of decision-making criteria and options.

Identified Stakeholders included:

- Public Agencies (states, MPOs, cities, transit authorities)
- Government leaders, elected officials;
- Chambers of Commerce, Freight/Carriers, Business Leaders
- Economic Development Leaders (incubators, developers)

- Urban Planners
- Educational Institutions (school districts, colleges, universities)
- Business Travelers
- Logistics, Trade and Technology

Stakeholder meetings were held in:

- Cleveland
- Chicago
- Pittsburgh
- Youngstown
- Sandusky
- Toledo

10.5.1 Public Engagement

The Public Engagement strategies provided maximum coverage to all the communities along the corridor through various outreach approaches including informational sessions; virtual reality demonstrations on the technology; and digital platform project information and surveys. The results included public comments were residents gave input regarding their concerns and interest of the Great Lakes Hyperloop system. Input ranged from passenger experience use for personal and business travel, future freight movements and capabilities, and the development of a new transportation route connecting communities from Cleveland, Chicago and Pittsburgh.

The aim of the public engagement was to inform and gather feedback from community members along the corridor and create ongoing communications to support public participation.

10.5.2 Public Participation Goals

Inform

- To provide the public with balanced and objective information to assist them in understanding the problems, alternatives and/or solutions.

Consult

- Obtain public feedback on the feasibility analysis, alternatives or decisions

Involve

- To work directly with the public throughout the process to ensure that public issues and concerns are consistently understood and considered, and how the feedback influenced decisions

Collaborate

- To partner with the public in each aspect of the decision including the development alternatives and the identification of the preferred solution.

Empower

- To place final decision-making in the hands of the public

10.5.3 Tools of Engagement

Key Campaigns

- Built short, mid and long-term milestones for proactive engagements

Creative Assets

- Surveys
- Deliberate polling
- Virtual reality demonstrations;
- Newsletters

Location Niche Marketing

- FAQs
- Fact Sheets

Social Media Marketing

- Viral videos
- Share reactions
- Followers
- Trusted resource

Public Endorsements

- Put a human face on Hyperloop
- Testimonies
- Digital or print
- Live feeds
- Postings

Announcements

- Media actions; partner exclusives

- Frame and shape the messaging
- Press conferences at every milestone

Governmental Digest

- News briefs and related messaging from elected officials
- Impacts to project
- Campaign

Several public engagement events have been completed during the development of the feasibility study.

Film Festival Event

- Virtual reality experience engaging the public (April 2018)
    - To get a sense of what hyperloop travel would feel like
    - To experience moving through a hyperloop station
- Participants completed pre- and post-experience surveys
- 412 people participated

Pre-survey: While waiting in line, each attendee was required to take a short, four (4) question survey as a "ticket" to the experience.

Virtual Reality Experience itself: this is an important engagement tool to help people visualize the Hyperloop and increase awareness and support for the project.

Post experience:

- Exit Survey – After experiencing the Hyperloop virtual reality, four questions to determine if their perception of the Hyperloop changed.
- Social Media – Attendees will be invited to "tweet us" about their experience with the hashtag #GreatLakesHyperloop. Appropriate responses will be retweeted by both NOACA and HyperloopTT.

Takeaways: "Tweet Us" card. Hyperloop branded stickers and postcards provided for takeaway.

S**urvey Questions**

Pre-Experience Survey

Please rate how strongly you disagree or agree with the following statements.

Strongly disagree Strongly agree

1. I am familiar with the Cleveland to Chicago Hyperloop project. 1 2 3 4 5

2. Cleveland to Chicago Hyperloop is a good idea.	1	2	3	4	5	
3. Cleveland/NEO should be one of the first in the country get this new method of travel.	1	2	3	4	5	to
4. If a Hyperloop route existed between Cleveland and Chicago, I would consider using it.	1	2	3	4	5	

5. When I think of Hyperloop, words that come to mind are:

____

Post-Experience Survey

Now that you have experienced the virtual-reality Hyperloop, please rate how strongly you disagree or agree with the following statements.

	Strongly disagree			Strongly agree		
1. I now have a better understanding of the Cleveland to Hyperloop.	1	2	3	4	5	Chicago
2. I think the Cleveland to Chicago Hyperloop is a good idea.	1	2	3	4	5	
3. Cleveland/NEO should be one of the first in the country to get this new method of travel.	1	2	3	4	5	
4. If a Hyperloop route existed between Cleveland and Chicago, I would consider using it.	1	2	3	4	5	

5. When I think of Hyperloop, words that come to mind are:

____

Results:

Over 97% of respondents thought the Hyperloop between Cleveland and Chicago was a good idea. Over 97% of respondents believed Cleveland should be one of the first in the country to get this new method of travel. Over 90% of respondents indicated they would ride the Hyperloop if a route existed between Cleveland and Chicago.

10.6 Outreach

Cleveland Public Meeting

In transportation there are iterations, and then there are breakthroughs. Ultra-high-speed transport – like Hyperloop – has the potential to change our city and our region. Join members of the community and NOACA to discuss and creatively represent how connecting Cleveland and Chicago in under 30 minutes might change our city. Draw what you think the future of transportation will look like and share what makes it important to you. We encourage families and children to attend! Hotdogs provided!

November 18, 2019; 6:00 – 9:00 pm

Attendees were provided an overview of the project, with presentations from NOACA's Executive Director, Hyperloop Transportation Technologies Leadership. Attendees were also asked to provide input on potential station locations.

10.7 Consortium

GREAT LAKES HYPERLOOP CONSORTIUM

The necessary ingredients to enable a successful launch of something as transformative as the hyperloop, and sustaining its growth for years to come, includes having a foundation of the best and the brightest across industry, academia and all levels of government. The Great Lakes Megaregion is fortunate to have an abundance of relevant stakeholders from all of these disciplines. The visionaries that have come before are the inspiration for this present day Great Lakes Hyperloop Consortium -- entities bound together with a common purpose of supporting the advancement of a new mode of transportation in the birthplace of aviation.

As part of this initiative, a growing number of regional stakeholders including industry leaders, academia, national labs, non-profit, for-profit and government entities formed the Great Lakes Hyperloop Consortium. Members not only support the project but are committed to making the Hyperloop a reality.

GREAT LAKES HYPERLOOP CONSORTIUM MEMBERS

1. Additive Engineering Solutions
2. America Makes – National Additive Manufacturing Innovation Institute
3. Case Western Reserve University (CWRU)
4. City of Akron, Ohio
5. Cleveland State University (CSU)
6. Eaton
7. Eureka! Ranch International
8. The Gateway Group
9. The Great Lakes Science Center
10. The Greater Akron Chamber
11. Impossible Objects, Inc.
12. Jobs Ohio
13. Minnesota USA EXPO 2027
14. Neil Armstrong Chair of the Ohio State University
15. Ohio Aerospace and Aviation Council (OAAC)
16. Ohio Aerospace and Aviation Technology Committee (OAATC)
17. Ohio Aerospace Institute (OAI)

18. Ohio State University
19. Parker Hannifin
20. Team NEO
21. University of Akron
22. University of Akron Research Foundation
23. University of Cincinnati SpaceX Hyperloop Competition Team
24. Wright State Research Institute
25. ZIN Technologies
26. BioEnterprise
27. Kent State University

10.7.1 National/State Conferences

The Study Team presented at the following conferences:

- Association of Metropolitan Planning Organizations (AMPO)
- Transportation Research Board (TRB)
- Ohio Transportation Engineering Conference (OTEC)
- Ohio Freight Conference
- National Association Regional Councils (NARC)
- Local Business or Engineering Groups

Chapter 11

Conclusions and Next Steps

Summary

This chapter outlines the key findings of the study, and the next steps that should be taken to move the Cleveland Hyperloop Corridor project forward.

11.1 Summary of Findings

Hyperloop, as a fifth mode of transportation offers a new dimension to intercity passenger and freight transportation. This study evaluated the potential of the Hyperloop Transportation Technology (HyperloopTT) system for linking Cleveland from Chicago and Pittsburgh and found that if the system uses a four-meter tube there is a very strong case for developing the system. HyperloopTT provided technical specifications for linear infrastructure in which TEMS found a very strong economic case for developing the project based on the lower relative costs for construction of the HyperloopTT system, the overall benefits of sustainable ultra high-speed mobility throughout the region, and the possible community development tools available to cities via hyperloop-enabled mobility oriented development. The HyperloopTT four-meter tube technology provides a capability to dramatically change intercity transportation.

- First it offers a very fast, 500-600 mph average speed, ground transportation system that can reduce the pressure on intercity interstate highway system, which is currently reaching capacity. At the same time, it offers an energy efficient means of transportation that reduces dependence on fossil fuels and can be powered completely by renewable energy sources.
- Second, it increases flexibility in transportation modal choice, and is attractive enough to significantly reduce dependence on auto and truck modes of transportation. Hyperloop can competitively attract large market shares from auto and truck that are the overwhelming dominant modes of travel in today's transportation markets. This allows Hyperloop to effectively absorb a large part of future transportation needs in intercity corridors.
- Third, as in the case of interstates and airports, Hyperloop will provide new transport accessibility, which will transform the economy, adding significantly to economic growth, and reconfiguring the economy to the New Economy requirements for IT, software, computers, logistics, financial and service industries that the US economy will increasingly rely on in the future. As with the interstate highway system, the building of a national Hyperloop system network could add as much as one half to one percent increase in Gross Domestic Product (GDP) due to its productivity, efficiency, social and demographic changes. It may well change cities in the way the interstate system changed cities, but rather than inducing sprawl and beltways, will induce the expansion and renewal of city centers and medium size town across the country.

Specifically, this study found that if the Hyperloop system is developed, representative routes can be developed that for the four meter tunnel option, would result in considerable underground construction (tunnel cut-and-cover), and similar to many pipelines would be buried from view on routes that include sections alongside toll roads and highways, railroads, electric utility rights-of-way and greenfields.

The average speed of Hyperloop would be between 500-600 miles per hour through the flatlands of the Midwest and 400-500 miles per hour in the hills and mountains of Appalachia. This gives scheduled travel times (including slack time) of 40 minutes from Cleveland to Chicago and 30 minutes from Cleveland to Pittsburgh. Times to intermediate locations like Toledo, Youngstown, and South Bend are equally fast with Cleveland to Toledo being 20 minutes, Cleveland to Youngstown 20 minutes, and South Bend to Chicago 20 minutes. This will dramatically increase the integration of the cities of the corridor and spur population, industrial development and economic growth.

In terms of the market for Hyperloop there are two principal elements; ridership and freight.

- **Ridership.** The intercity Cleveland-Chicago-Pittsburgh travel market is estimated to grow from 40 million trips to 50 million trips by 2050 or by 25 percent. It is calculated that Hyperloop market share will be 12 million in 2020 rising to 17 million by 2050. This means Hyperloop will be able to absorb all the intercity traffic growth in the corridor between 2020 and 2050 taking pressure off the interstate highway system. The associated revenue will be over $900 million in 2020 using the $1300 million by 2050. The main sources of Hyperloop traffic are 48% diverted from automobile, 6.8% natural growth, and 30% induced traffic.

  While a fare strategy has yet to be finalized, for business travel fare levels are expected to be lower than the Northeast Corridor high-speed rail fares; but for social and leisure travel, fares will be similar to or lower than the level of fares that Amtrak typically charges in the Midwest for its 79-mph service. Fares will be about 60 percent of air fares.

- **Freight.** The 4-meter tube proposed by HyperloopTT would allow three types of traffic to be carried by Hyperloop; Air Cargo, Less-than-Truckload freight and Express Parcel. Air Cargo is growing at 4-6 percent per year, while Express Parcel is growing at 15 percent. Both of these forecasted rates of increase are much faster than the growth of passenger traffic. On the other hand, freight was costed on an incremental basis since fixed costs of the system, such as sales and marketing, service administration, guideway operations and maintenance, and station costs have already been paid for. Therefore, the main elements of freight costs are terminal costs for loading and unloading vehicles, equipment maintenance and energy. There is no crew cost associated with freight since these capsules can operate unattended. It was projected that freight costs would come to 10¢ per ton mile, which is highly competitive with trucking costs, therefore the freight service should be able to attract substantial volumes of freight from the highways.

TEMS conducted its Financial and Economic Analysis using USDOT FRA and Tiger Grant methodology. TEMS found that the tollway route with the most stations produced a very strong operating ratio of 4.15 for the life of the project, well over the breakeven cost and making an operating profit of $30 Billion over the life of the project. TEMS found that freight traffic has a significant impact on the cash flows for an interstate hyperloop corridor, which effectively doubles the passenger revenues. At a 3% discounting rate, the Financial return (NPV) would be $6.6 Billion for a total cost NPV of $33 Billion.

In terms of Economic Benefits, the project shows a Cost Benefit Ratio of 2.15 at 3% discount rate and 1.34 at a 7% discount rate or Net Present Value (NPV) of $38 Billion at 3% and $9 Billion at 7%.

These strong results would allow a public/private partnership to be developed, as the Hyperloop system can be operated profitably, and could make a substantial contribution to Capital Cost. It is likely that Wall Street would require a government contribution to senior debt, or at least a ridership revenue guarantee as was used for the English Channel tunnel. As a result, HyperloopTT shows a strong Public/Private partnership potential.

Finally, the Supply-side Analysis of Economic Benefits showed that the project would generate –

- 931,745 man years of work
- $47.5 Billion in added income
- $74.8 Billion in added property value

11.2 Next Steps

Hyperloop is a new fifth mode of transportation that has not in the past been recognized by USDOT. Recently, however, USDOT has set up the Non-Traditional and Emerging Transportation Technologies (NETT) Council. The NETT Council is developing both a regulatory framework and support system for Hyperloop technologies, which only exist today for traditional modes. In the absence of NETT procedures for Hyperloop this study has been completed using typical USDOT procedures. The next steps for the Great Lakes Hyperloop project would be to undertake an Environmental Impact Study (EIS) at the Tier 1 level using FAST ACT evaluation procedures. This might be led and financed by one of the traditional mode departments (e.g., FHWA, FRA, etc.) or possibly the Surface Transportation Board (STB). In any circumstances the use of the Tier 1 process would be effective as it allows the corridor to be segmented into different environmental types. This would allow the process to identify areas of limited or no impact and separate them from areas of moderate or significant impact. Furthermore, as the corridor spans four states it allows segments in different states to be evaluated in terms of their own state requirements, which may be common between states or need special treatment.

Typically, the requirements of a Tier 1 study would be –

- **Project Work Plan and Schedule** – this would develop a "road map" identifying the major issues that will have to be addressed by the Tier 1 NEPA planning process, so that the level of effort and time frame required for completing the Phase 2 study can be accurately assessed, and to optimize the cost and delivery time frames for the proposed Phase 2 project. A key deliverable will be the "Purpose and Need" for the study.
- **Communications Plan** – Develop and implement a Communications Program. This would involve working closely with stakeholders and the public. Key stakeholders will include USDOT, State DOT, railroads, transportation agencies such as turnpike authorities and MPO's and other partners critical to the development of an effective program.
- **Alternatives Definition** – Three representative corridors have been evaluated previously as part of the Hyperloop feasibility study, but they need more detailed review in relation to route refinement, infrastructure needs and environmental impacts. It may also be desirable to develop additional route options for consideration. These optimized routes would be critical components of the planning.
- **Interactive Analysis** – The determination of appropriate Hyperloop service depends on balancing the trade-off between revenues and costs for any given route and technology. A key determination to make during this stage is whether to pursue shallow-tunneled (e.g. cut-and-cover) or deep tunnel alignment for any given segment of the route. This will also afford a possible opportunity to straighten out segments of the route which might otherwise need curves if they are going to be constructed on the surface.

- **Passenger and Freight Market Assessment** – The freight and passenger models that were developed for the feasibility study will need to be further tested and refined. For example, this may include a more detailed assessment of -
    - A Stated Preference Survey of air, hyperloop, rail, bus and auto travelers in the corridor.
    - The detailed characteristics of particular target markets such as daily commuters, air connect riders, business travelers, students and corporate groups, and how they travel. Including the development of revenue yield assessments for specific types of travelers, e.g. commuters, shoppers, etc.
    - Further refinement and evaluation of the freight strategy, including for example further assessment of the market for truckload freight, and the optimization of service and marketing options for attracting such freight to use the system.
    - Identify existing connecting transit services and consider the development of additional “last mile” connections as appropriate and the ability to integrate with regional transit and airports.
- **Operations and Capital Cost Refinement** – The capital and operating plans for both freight and passenger services will be further refined –
    - Develop detailed pro-forma operating schedules and plans detailing the precise infrastructure requirements.
    - Consider freight requirements in more detail.
    - Further develop the feasibility of alternative station sites in conjunction with considerations for value capture and how that may affect the financing and funding ability for building the system.
    - Complete a station location study with a particular view to optimizing the real estate development and value capture opportunities associated with the implementation of the service.
- **A Financial/Economic and Funding Plan –**
    - Enhance the benefits assessment to reflect the fact that infrastructure investments will be mutually supportive to all travelers.
    - A collaborative approach would help facilitate a better understanding of the synergies between the needs of different corridor users.
    - Developing a single integrated Cost Benefit calculation would avoid the need for developing allocations of shared costs, which often tend to be arbitrary.
    - Assessment of Transit-Oriented Development for specific stations along the route.
    - This offers the best prospect for accelerating the time frames for badly needed infrastructure improvements.
- **Environmental Scan/Service NEPA and Service Development Plan –** these two documents will likely be required for eligibility for further USDOT funding. A preliminary assessment or “environmental scan” is needed to identify the key issues associated with the development of each alignment option and develop a project management strategy and approach for dealing with each of these issues and segmenting the corridor in terms of environmental conditions. The Service Development plan explains to USDOT what the proposed system and service are and how it would work. This document will assist in making an initial determination of what kind of an approach will be needed to resolve the environmental issues associated

with each segment of the route. This preliminary assessment will also serve as a Scoping Study for the much larger Tier 2 effort.

- **Project Implementation Plan –**
    - Consider the potential for a PPP/franchise in order to attract private capital to the project. Develop a preliminary funding plan.
    - Develop a detailed Implementation Plan, outlining the short- and long-term actions that need to be taken to initiate service. This includes identifying the development steps of the corridor and aligning that with a funding plan, to allow the project to be phased in the most effective manner.

The aim should be to obtain funding for the next step of developing the Environmental case as quickly and effectively as possible.