HYPERLOOP TECHNOLOGY: ECONOMIC ANALYSIS OF A TRANSPORTATION REVOLUTION

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This thesis analyzes several aspects of the Hyperloop technology, with a focus on assessing the technological and economic feasibility of the proposed system. Although there are numerous Hyperloop routes under current consideration, this study concentrates on valuating the proposed San Francisco to Los Angeles route. From a technological standpoint, this study concluded that there are many engineering concerns and external risk factors associated with the design of the Hyperloop, which limit the viability of the system. Furthermore, the economic feasibility study established a rough valuation for the proposed route through a DCF analysis. It was determined that the project would be operationally profitable in each of the nine scenarios, under both discount rate assumptions. After taking into consideration the initial capital construction costs of the project, however, the study concluded that only six scenarios were net present value positive under the lesser discount rate assumption.
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In August 2013, Elon Musk introduced his revolutionary transportation concept to the public through the release of a preliminary design study. The “Hyperloop” concept, described in the white papers, was designed to be the ultimate mode of transportation. The proposed technology would combine magnetic levitation and an air-bearing suspension system, in order to levitate a pod-like passenger or freight capsule in a closed-system tube. Commercial grade vacuum pumps would be used to create a low-pressure environment within the Hyperloop tubes, which would effectively reduce the force of drag—allowing numerous linear induction motors to propel capsules through the tube at transonic speeds. The tubes would be placed on pylons, which would suspend the track above the ground, incorporating a vertical and horizontal dampening system to lessen the risk from earthquakes. In addition, the entire system would feature a large solar array that would be fastened to the top of the tube and provide self-sustainable power generation to support the energy requirements during operation.

Within the white papers, Elon Musk described the advantages of the proposed Hyperloop design over existing forms of transportation and recommended the development of an initial route between San Francisco to Los Angeles. The proposed route would be approximately 350 miles in length and run parallel to the California Interstate 5 highway, benefitting from the existing infrastructure from a cost perspective. It was estimated that the total travel time between the two cities would be approximately 35 minutes. The preliminary design study projected a
rough estimate of $6 billion for the total construction costs associated with building a passenger Hyperloop route along this region in California.\textsuperscript{23}

This thesis will examine several aspects of the Hyperloop concept, with a focus on gauging the technological and economic feasibility of the proposed system. Chapter 2 will introduce the major components of the Hyperloop, describe the functionality of the system, discuss the current developments being made, and analyze several strategic concerns that limit the viability of implementation. Chapter 3 will compare the freight versus passenger version of the Hyperloop and examine several prospective routes that are currently under consideration. Chapter 4 will compare the Hyperloop system to four existing modes of transportation and explain various benefits associated with the Hyperloop along the proposed route. Chapter 5 will forecast consumer demand, estimate an appropriate ticket-pricing scheme, and build a dynamic model to analyze the potential revenue that would be generated by the San Francisco to Los Angeles route. Chapter 6 will forecast fixed maintenance and variable operating costs, as well as the total implementation costs, and build a dynamic model to analyze the operational profitability of the proposed route. Chapter 7 will outline our DCF model, explain various assumptions, and deliver a sensitized analysis of the Hyperloop valuation, which considers the effects of several variables on the profitability of the system. Chapter 8 will summarize the results of the entire study.
Chapter 2
Technological Feasibility

Major Components of Hyperloop

There are three major design components of the proposed Hyperloop Transportation System. This section will explore each of these individual components, as well as the subcomponents that are necessary for propulsion, drag reduction, and power supply.

Component 1: Capsule

The purpose of the Hyperloop capsule is to safely transport up to 28 passengers through a tube within a low-pressure environment at speeds of up to 760 mph (Mach 0.91). One of the biggest concerns associated with the design of the capsule is the aerodynamic flow of the system. Since the entire system is closed, the displacement of air within the tubes must be considered, as it could limit the movement of the capsule through the system. When travelling at transonic speeds, the cross-sectional area and diameter of the capsule in comparison to that of the tube is of critical importance. If the diameter of the capsule is too large with respect to the tube with which it is travelling through, the space between the capsule and the interior walls of the tube will be too small to allow the displaced air to flow behind the capsule as it is projected forward. Essentially, this design would cause a “choke” to the flow of air in the tube. Thus, engineers designing the Hyperloop must work to optimize this tube-to-pod area ratio toward the “Kantrowitz Limit”, which defines the maximum velocity of a capsule through a tube based on
the respective cross-sectional areas of the capsule and tube. The proposed Hyperloop passenger
capsule will be designed to feature a maximum width of 4.43 ft (1.35 m) and maximum height of
6.11 ft (1.10 m). This will balance the need for passenger comfort with the cost of material
associated with the capsule’s design, while also optimizing the potential speed of the capsule
through the system.

Figure 1. Conceptual design sketch of Hyperloop passenger capsule

Aside from the tube-to-pod area ratio, the aerodynamic design is also critical to reduce
the drag force produced at maximum velocities within the tube’s low-pressure vacuum
environment. The conceptual design sketch, shown above, demonstrates the streamlined design
of the front of the capsule, which is important in reducing the drag coefficient. Additionally, the
overall weight of the capsule’s structure is estimated to be roughly 6,800 lb (3,100 kg).
1a. Electric Compressor Fan System

The first key subcomponent of the Hyperloop capsule is the electric compressor fan system. The compressor fan is placed at the front of the capsule, behind the inlet that directs the airflow through the fan. The compressor serves three main purposes—to increase the speed of airflow from the front to the rear of the capsule, to compress air to be used within the air bearing suspension system, and to propel the capsule forward.

Considering the Kantrowitz limit, as well as the velocity-limiting effect that is produced as high-pressure air builds up in the front of the capsule, the compressor fan becomes the obvious solution for transferring the high-pressure air from the front to the rear of the capsule. Thus, the compressor fan mitigates this velocity-limiting effect, allowing the capsule to travel at greater speeds. The figure below demonstrates how the airflow is directed both around the capsule in the space between the capsule and the tube, as well as through the capsule, by way of the compressor fan system.
The second objective of the compressor system is to compress air to be used within the air bearing suspension system to support the weight of the capsule throughout the trip. As air is directed through the inlet into the compressor fan, roughly 40% of the air is compressed through an axial compressor with a compression ratio of 20:1. The compressed air is then cooled and stored in a specialized composite pressure vessel, before being directed to the air bearing suspension system. The air bearing system then uses the pressurized air to produce an “air cushion” which supports the weight of the capsule and controls the distance between the capsule and the tube walls. The remaining 60% of the air is circumvented via a tube that runs along the bottom of the capsule. This pressurized air is projected out of the rear of the capsule via a specialized nozzle that produces small amounts of thrust to propel the capsule forward. This compressor fan is powered by a 436 hp (325 kW) electric motor that sits directly behind the fan within the capsule.

1b. Air Bearing Suspension System

The next key subcomponent of the Hyperloop capsule is the air-bearing suspension system. In order to travel at transonic speeds, the Hyperloop must reduce the frictional
force between the capsule and the tube walls. Traditional methods for reducing friction include both the use of conventional wheels, as well as the use of magnetic levitation, such as in the case of the Maglev train. At transonic speeds, however, the use of conventional wheels would be infeasible and prone to damage. On the other hand, magnetic levitation would be feasible at transonic speeds, but is much more expensive to implement. The only practical solution is an air bearing suspension system.

The proposed design of the Hyperloop capsule incorporates the use of 28-air bearing “skis” which are fitted around the exterior of the capsule. The air bearing suspension system supports the weight of the capsule by creating an air cushion that levitates the capsule roughly 0.5 to 1.3 mm above the tube. Each air-bearing ski is 4.9 ft (1.5 m) in length and 3.0 ft (0.9 m) in width.23

![Figure 4. Schematic of air bearing skis](image)

The figure above demonstrates the air bearing system as it produces a thin cushion of air to suspend the capsule. The suspension is driven via two modes—the release of pressurized air and the controlled aerodynamics of the capsule. At low speeds, high-pressure air from the composite pressure vessel is released through small slits on the bottom surface of the air bearing skis. Depending on the weight of the fully loaded capsule, air is pumped out of the skis at a rate exceeding 0.44 lb/s at 1.4 psi. This produces
enough lift to suspend the capsule and reduce the frictional force. At higher speeds, the aerodynamics of the capsule can also be controlled in conjunction with the release of pressurized air to produce adequate suspension. Using this method, as the capsule accelerates to higher speeds through the tube, the front tips of the air bearing skis are lifted to form a small angle between the skis and the tube walls. This slight angle produces a pressurized stream of air beneath the capsule that creates a lifting force. The weight of the entire air bearing system is estimated to be roughly 6,200 lb.23

**1c. Rotor**

The third key subcomponent of the Hyperloop capsule is the rotor, which is also a subcomponent of the propulsion system. The rotor is a 49-foot aluminum blade that is fixed on the exterior and runs along the bottom of the capsule. The rotor works in conjunction with the stator as part of the linear induction motor system to create a magnetic field, which propels the capsule forward. The gap between the rotor and the stator is set at about 0.8 inches on either side, and the electromagnetic field also serves to maintain a precise centric positioning of the capsule within the tube.

**1d. Battery**

The fourth subcomponent of the Hyperloop capsule is the battery. In order to power the electric compressor fan system, a 5,500 lb battery system is required. The battery system is contained in the rear interior of the capsule, behind the passenger compartment.

**1e. Passenger Compartment**

The last key subcomponent of the Hyperloop capsule is the passenger compartment. The proposed interior of the passenger compartment will contain two rows of 14 seats,
creating a capacity of 28 passengers per capsule. Each of the seats will be designed with safety and passenger comfort in mind. Additionally, each passenger seat will include a personal entertainment system. The total estimated weight of the interior components is roughly 5,500 lb.23

![Conceptual design sketch of passenger capsule with gullwing door design](image)

*Figure 5. Conceptual design sketch of passenger capsule with gullwing door design*23

The figure above shows the interior design of the passenger compartment, as well as the design of the gullwing doors, which will allow passengers to enter and exit their particular seat quickly at the station.

**Component 2: Tube**

The next major component of the Hyperloop is the tube. If constructed over the proposed San Francisco to Los Angeles route, the tube will stretch over 350 miles in both directions, providing a low-pressure environment that will allow capsules to travel at speeds in excess of 760 mph. The tube itself will be constructed of specially designed steel, which is then reinforced
with stringers. Additionally, the thickness of the tube walls will be at least 0.8 inches to ensure their necessary strength. As described earlier, the Kantrowitz limit was carefully considered when designing the dimensions of the tube. Ultimately, Hyperloop engineers determined the optimal inner diameter of the tube to be 7.3 feet, in order to minimize material cost, while maintaining the ideal tube-to-pod area ratio. With regards to construction, pre-fabricated tubes will be assembled atop pylons and welded together using an orbital seam welder. Two 350-mile tubes will run parallel to each other to allow travel in either direction, and pylons will be positioned roughly every 100 feet to support both of the tubes. In order to produce a low-pressure environment, commercial vacuum pumps will be spaced periodically along the tube, as well. The vacuum pumps will continually operate to maintain a constant pressure of roughly 0.015 psi.23

[Image: Hyperloop tube connecting San Francisco to Los Angeles]

In order to power these vacuum pumps as well as the propulsion system, the Hyperloop will incorporate the use of solar panels and a battery storage system as a sustainable source of energy. Another important design element of the tube is the overall geometry of the tube. Since capsules will be traveling at transonic speeds through the tubes, any sharp bend in the tube’s path
would cause passengers to experience uncomfortable inertial acceleration effects. Thus, it is crucial to choose a route for the tube that would limit any curvature in the design of the path.

2a. Pylons

The first subcomponent of the Hyperloop tube is the pylon. The pylons are necessary as a foundation for the tube to be built upon. The primary purpose of the pylons would be to elevate the tube above the ground and maintain as straight of a path as possible, in order to limit any negative inertial effects described above. An advantage of using pylons for the San Francisco to Los Angeles route is that it would allow the Hyperloop to be built alongside the California Interstate 5 highway, minimizing the cost of land by utilizing existing infrastructure. Since that particular stretch of the highway is relatively straight, minimal work would be required to develop a linear path for the tube.

![Figure 7. Conceptual design sketch of Hyperloop pylons](image)

In total, roughly 25,000 pylons will be spaced at about 100 feet apart along the entire 350-mile path. The pylons will be constructed of reinforced concrete to reduce the total
cost. On average, the pylons will be about 20 feet tall, but will be designed to vary in height in order to maintain a linear path for the tubes above the ground. Furthermore, each pylon will integrate two adjustable lateral dampers and one vertical damper to reduce the risk associated with any type of ground movement, such as an earthquake—which is particularly prevalent in California.

2b. Propulsion System

The next key subcomponent of the Hyperloop tube is the propulsion system. In order to propel the capsules through the tube at transonic velocities, a magnetic linear induction motor is secured throughout several sections of the tube. External linear electric motors are placed about 70 miles apart along the length of the tube and continually accelerate the capsules through the tube. Engineers estimate that the combined length of the external linear electric motor will only span roughly 1% of the entire tube, and therefore, will not be too expensive of a subcomponent. The type of linear accelerator used will depend on its particular position along the tube. Small linear accelerators will be used along the first section of the tube to provide initial acceleration from 0 to 300 mph, as well as during sections of the tube that traverse urban areas. Larger linear accelerators will be used along later sections of the tube to accelerate the capsules from 300 to 760 mph. Linear accelerators will also be used to decelerate the capsules before entering the station.
The propulsion system is comprised of the linear induction motor, the inverters, the stator, and the rotor—which is fixed to the exterior of the capsule. The diagram above demonstrates how the stator surrounds the rotor on both sides and manipulates the magnetic field to propel the capsule forward. The gap between the rotor and the stator is set at about 0.8 inches on either side, and the electromagnetic field also serves to maintain a precise centric positioning of the capsule within the tube. The stator is composed of highly ferromagnetic iron and is roughly 1.6 feet wide and 4 inches tall.23

2c. Solar Panel System

The third subcomponent of the Hyperloop tube is the solar panel system. The purpose of the solar panel system is to supply enough energy to provide self-sufficient power to the entire Hyperloop system. The total average power requirement for the Hyperloop is 28,000 horsepower.23 This includes the energy required for powering the
linear induction propulsion system, charging onboard batteries, and powering the commercial vacuum pumps.

As shown above, the solar panel array will be mounted to the top surface of the parallel tubes. Assuming the solar array spans the entire 350-mile length with a width of 14 feet, the total area of the array would be over 25 million square feet. With current solar panel technology producing energy at 0.015 hp/ft², the solar array will be capable of producing over 380,000 horsepower during peak solar periods. On an average basis over the course of one year, it is estimated that the Hyperloop solar panel system would produce 76,000 horsepower. Thus, the solar energy generated by the solar array will be in excess of the average 28,000-horsepower requirement of the entire Hyperloop system. The system will incorporate the use of battery packs to store energy for use overnight and during periods of cloudy weather. Furthermore, power can also be pulled from the grid as a last resort.
2d. Vacuum Pump System

The final subcomponent of the Hyperloop tube is the vacuum pump system. The purpose of the vacuum system is to produce a low-pressure environment within the tubes that will reduce the drag force applied to the capsules and allow them to reach transonic speeds. Multiple commercial vacuum pumps will be spaced periodically along the tube and will continually operate to maintain a constant pressure of roughly 0.015 psi.23

Component 3: Station

The purpose of the Hyperloop station is to provide an efficient mode of boarding the capsules. Although no particular design has been set in stone, engineers are working to design a simple station that will minimize each passenger’s total time spent in transit. In contrast to an airport, the flow of passengers through the station will be more constant as the average time between each departure will be about 2 minutes, as compared to significantly longer times between each departure at an airport. Thus, the Hyperloop stations must be streamlined in order to compensate for higher efficiency throughput requirements. Modernized security systems and automated ticketing and luggage storage processes will be used in part to support this initiative.
For the San Francisco to Los Angeles route, two major stations would be built at both locations with the potential for several other stations to be built along the route at high population cities, such as San Jose, San Diego, Sacramento, and Fresno. The stations will be designed to support a maximum capacity of 840 passengers per hour. From an engineering perspective, there are many logistical issues associated with loading and unloading each capsule while maintaining a low-pressure environment in the tubes. Two airlocks will be incorporated into the design of each station. The departure airlock would seal the capsule in a special compartment of the station and reduce the atmospheric pressure to match the exact air pressure in the tube. The capsule would then be accelerated towards the destination. The arrival airlock, on the other hand, would seal the capsule after it arrived at its destination and equalize the pressure in the tube to match the atmospheric pressure in the station. The passengers could then safely exit the capsule.
Current Development

There are currently two main players in the Hyperloop space—Hyperloop Transportation Technologies (HTT) and Hyperloop One. This section will investigate each of these two companies individually and assess the progress that has been made thus far.

Hyperloop Transportation Technologies (HTT)

Hyperloop Transportation Technologies (HTT) was founded in November 2013, by a crowd collaboration platform known as JumpStartFund. The unique structure of the company combines the efforts of over 600 team members, with a variety of expertise, and 40 corporate partners from around the globe. The firm operates internationally, with offices in Los Angeles, Barcelona, Abu Dhabi, and Bratislava. Early on, HTT announced that it would concentrate on projects that would implement the technology in a variety of regions around the world, as opposed to focusing solely on the San Francisco to Los Angeles route. Since inception, HTT has raised more than $100 million in total investment—including roughly $32 million in cash from investors. The rest of the investment is comprised of a mixture of labor, costs associated with land rights, and services provided by partner firms.

In December of 2016, HTT announced an agreement with Abu Dhabi’s Department of Municipal Affairs and Transport to begin a feasibility analysis for the design of a Hyperloop system connecting Abu Dhabi to Al Ain. The study will focus on pinpointing strategic locations for the Hyperloop stations, determining optimal routes, estimating implementation costs, and ascertaining a rough schedule for development.
On January 14th of 2017, HTT announced a strategic agreement with the city of Toulouse, France to convert a 3,000 square meter former military base into a new HTT Toulouse Research and Development Facility. This marked a crucial collaboration for Hyperloop Transportation Technologies, as HTT COO Andres De Leon explained, “Our close relationship with the local government is exactly what is needed to implement Hyperloop systems in Europe. While developing our technology, we will also work together to create the necessary regulatory framework for the system”. Furthermore, the location of the facility is ideal, as Toulouse—colloquially termed “Aerospace Valley”—is recognized as the European center for research and development in aeronautics. Thus, the location would also be strategic to HTT for sourcing top engineers from the regional talent pool.

Days later, on January 18th, HTT announced an agreement with the city of Brno, Czech Republic to begin a feasibility analysis for the design of a Hyperloop system connecting Brno to Bratislava, Slovakia. This was a significant development for Hyperloop Transportation Technologies, as it marked the first proposal for a system that would connect two international cities. Naturally, the construction of this international route will be met with considerable regulatory hurdles, but it certainly marks a step in the right direction for HTT.

In March of 2017, Hyperloop Transportation Technologies announced that they would begin a similar feasibility analysis for the implementation of a Hyperloop system in Jakarta, Indonesia. The proposed systems include routes connecting Jakarta to Yogyakarta, Jakarta to Bandung, and Jakarta Soekarno-Hatta International Airport to the city center. The study will be funded by a $2.5 million contract from private investors.

With regards to full-scale production, Hyperloop Transportation Technologies has not seen much progress. In January of 2016, HTT announced that it had begun the process of filing
construction permits in Kings County, California. The initial plan was to begin construction of the first passenger-ready Hyperloop system in Quay Valley, California in mid-2016. Unfortunately, HTT has run into several regulatory setbacks since then which has delayed construction. Sandy Roper, the principal planner at the Kings County Community Development Agency, explained that, “[HTT] has not yet submitted an environmental review document for the project, and the agency cannot act without it. HTT would also need to overcome several more bureaucratic hurdles before it could be issued a building permit, such as a public comment period and approvals by both the board of supervisors and planning commission.” Thus, Hyperloop Transportation Technologies faces a tough regulatory environment going forward and will have to overcome a variety of obstacles, which will likely continue to delay full-scale production.

Hyperloop One

Hyperloop One, formerly known as Hyperloop Technologies, was co-founded by Josh Giegel and Shervin Pishevar in 2014. The company quickly gained traction as top talent was poached from some of the most prestigious engineering firms and investments poured in from various venture capital funds. By January of 2015, Hyperloop One moved its operations to its “Innovation Campus” in downtown Los Angeles. Currently, Hyperloop One has 230 full-time employees positioned at locations in Dubai, London, and both a “Test & Safety Site” and “Metalworks” manufacturing facility in Nevada. Since inception, Hyperloop One has raised more than $160 million in total investment.

On May 11, 2016, Hyperloop One conducted a successful propulsion open-air test at its Apex Test site in North Las Vegas, Nevada. The test confirmed that the electromagnetic propulsion system was capable of accelerating a sled from 0 to 116 mph in 1.1 seconds.
Although the test track was only a fraction of the distance of the proposed design and completely lacked any braking mechanism, the test signified a vital proof-of-concept and marked a major milestone in the production of Hyperloop One’s full-scale linear electric motor.

In November of 2016, Hyperloop One began construction of the first full-scale Hyperloop test track in North Las Vegas, Nevada. The “DevLoop”, short for Development Hyperloop, will be approximately 500 meters long and feature all of the major components of the Hyperloop. Hyperloop One expects the DevLoop to be completed by mid-2017, allowing engineers to begin conducting various tests in order to optimize the levitation, propulsion, and vacuum technologies.

Hyperloop One is interested in implementing their technology in regions across the globe. The firm has conducted initial feasibility studies for routes in the United States, Russia, India, Switzerland, Sweden, the Netherlands, and in the UAE. Hyperloop One has specified that their overall goal is to be “moving cargo by 2020 and passengers by 2021”, although this timing sounds relatively ambitious given the number of technological issues and regulatory obstacles presented by the project.

**Strategic Concerns**

As with any revolutionary technology, there are a number of things that must be taken into consideration and carefully planned to ensure that the end product meets expectations. From an engineering standpoint, there are many logistical concerns associated with the design of the Hyperloop. This section will cover several of these engineering design concerns, external risk factors, and legal issues that threaten the viability of the technology.
Design Concerns

1. Infeasibility of the vacuum system

There are several issues inherent with designing the largest vacuum system in the world. Currently, the largest vacuum chamber is the Space Power Facility at NASA Glenn Research Center's Plum Brook Station in Sandusky, Ohio. The vacuum chamber measures 100 feet in diameter and is 122 feet tall. By comparison, the total volume of the Hyperloop vacuum would theoretically be over 60 times larger than the current largest vacuum chamber in the world. Additionally, NASA’s vacuum chamber is only designed for an internal pressure of 5 psi, versus the Hyperloop, in which the proposed design would feature a constant internal pressure of roughly 0.015 psi. The sheer degree of precision required for designing the world’s largest vacuum represents, perhaps, the most relevant design concern of the Hyperloop. After all, any small crack in the 350-mile tube, leak in any of the seals, or malfunctioning airlock would trigger the entire system to be flooded with pressurized air, causing catastrophic failure.

Another issue associated with creating a low-pressure environment would be the massive amount of atmospheric pressure applied to the exterior of the Hyperloop tubes. In fact, atmospheric pressure would exert over one ton of force per square foot onto the exterior of the tubes. This static force, combined with the frictional force of a 15-ton capsule travelling through the tube at transonic speeds would inevitably threaten the structural integrity of the steel tube walls—which are proposed to be less than an inch thick.
2. Temperature gradient causes expansion in tubes

Another design concern related to the construction of the Hyperloop is the fact that the steel tubes would expand and contract depending on the external change in temperature. The thermal expansion coefficient of steel is about 13 parts per million per degree Celsius. Assuming that the external temperature applied to the Hyperloop in California would range between 0 to 40 degrees Celsius on average from the coldest to the hottest day, the tubes would expand and contract by over 960 feet in length. Therefore, numerous expansion joints would be required to reduce the risk of structural buckling and maintain a closed system. Although expansion joints are effectively used to maintain the length of bridges throughout the world, there is a significant amount of complexity associated with designing expansionary joints that would also support the atmospheric pressure exerted on the vacuum seals in between each tube. Once again, any malfunction in any one of the thousands of expansion joints would trigger the entire system to be flooded with pressurized air, causing catastrophic failure.

*Table 1. Thermal Expansion Coefficients at 20°C*
3. Kantrowitz limit

As described previously, the Kantrowitz limit is another component of the Hyperloop design that must be taken into consideration. One of the biggest concerns associated with the design of the capsule is the aerodynamic flow of the system. Since the entire system is closed, the displacement of air within the tubes must be considered, as it could limit the movement of the capsule through the system. When travelling at transonic speeds, the cross-sectional area and diameter of the capsule in comparison to that of the tube is of critical importance. If the diameter of the capsule is too large with respect to the tube with which it is travelling through, the space between the capsule and the interior walls of the tube will be too small to allow the displaced air to flow behind the capsule as it is projected forward. Essentially, this design would cause a “choke” to the flow of air in the tube. Thus, engineers designing the Hyperloop must work to optimize this tube-to-pod area ratio toward the “Kantrowitz Limit”. The Kantrowitz limit defines the maximum velocity of a capsule through a tube based on the respective cross-sectional areas of the capsule and tube.

4. Any failure would cause catastrophic destruction

Perhaps the biggest drawback of the Hyperloop design is that any failure would cause catastrophic destruction. In the worst-case scenario, if one of the capsules became dislodged from the suspension system and ruptured a section of the Hyperloop tube, the pressurized air from outside would flood the tube causing a cascading effect that would destroy the entire system. As the pressure differential between the external and internal pressure of the tube would be roughly one atmosphere, air would rush into the tube at
approximately the speed of sound. Assuming that each capsule is separated by about 25 miles of track as it travels through the tube, the column of air would have a mass of roughly 100 tons. Thus, this shockwave would have devastating effects and likely kill every passenger travelling through the Hyperloop. This issue serves as one of the largest safety concerns surrounding the technology. In comparison to air travel, this is also one of the significant disadvantages of the Hyperloop, as even in the worst-case scenario related to air travel—one plane crash does not cause the destruction of multiple planes.

5. Logistics of loading and unloading at stations

From a design perspective, there are many logistical issues associated with loading and unloading each capsule, while maintaining a low-pressure environment in the tubes. The arrival and departure airlocks are critical components of the design of each station. If either airlock malfunctions, the entire Hyperloop system would be flooded with pressurized air, causing catastrophic failure.

6. Capsule depressurization

Another design concern that must be addressed is the risk of capsule depressurization. In the event of a minor leak in pressurization during travel, the Hyperloop would rely on a system that is similarly used on airlines. The installation of oxygen masks within each capsule would ensure that passengers could survive the rest of the journey through the tube, before safely reaching their destination. On the other hand, severe capsule depressurization poses a much larger risk and would likely kill every passenger onboard.
7. Peak hour congestion

The next logistical issue surrounding the Hyperloop involves the inherently variable passenger demand of the system. Although the proposed design of the entire Hyperloop system would support an 840 passenger per hour capacity, the design mistakenly assumes that there would be a constant distribution of passenger demand over time. In reality, passenger demand for the Hyperloop would likely spike during peak hours, such as rush hour. The increased demand during these peak hours would cause congestion, as a bottleneck would be formed at each station during periods in which demand surpassed the throughput capacity of the system.

8. Harmful inertial acceleration effects caused by curvature of tube

Another important design consideration of the Hyperloop is the geometry of the path with which the tube follows over its 350-mile route. Since capsules would be traveling through the tubes at transonic speeds, any sharp bend in the tube’s path would cause passengers to experience uncomfortable inertial acceleration effects. Thus, it is crucial to choose a route for the tube that would limit any curvature in the design of the path, such that, the maximum acceleration of the capsule is less than 0.5 G’s. As described earlier, pylons will be utilized to position the tube over varying surface gradients. Engineers will also have to rely on the construction of tunnels in certain regions where mountains limit the possibility for a straight path. As another technique to combat harmful inertial acceleration effects, capsules will be decelerated in specific regions where the path of the tube curves past a certain degree, such as to avoid a major metropolitan area.
9. Issues with suspension system

The next important design consideration of the Hyperloop is the suspension system. In order to travel at transonic speeds, engineers must design the system to reduce the frictional force between the capsule and the tube walls. Traditional methods for reducing friction include the use of conventional wheels and magnetic levitation. At such high velocities, however, the use of conventional wheels would be infeasible and prone to damage. On the other hand, magnetic levitation would be viable at transonic speeds, but comes at a much higher cost to construct. The only practical solution is an air bearing suspension system. This is easier said than done, however, as there are further design implications associated with the use of an air bearing suspension system. Although a rigid air bearing suspension system is necessary for providing safety by ensuring that the capsule does not come into contact with the tube walls, it would also provide less shock absorption and could cause an uncomfortable ride for passengers. Thus, it is important for engineers to incorporate the use of additional suspension systems in conjunction with the air bearing system to provide the most ideal ride for passengers.

External Risk Factors

1. Vulnerability to terrorism

Perhaps the greatest existential threat to the Hyperloop system would be terrorism. As described previously, any breach in the vacuum tubes would cause a catastrophic failure that would likely kill every passenger onboard. Since the proposed design of the Hyperloop would be built alongside the California Interstate 5 highway, it would be especially
vulnerable to terrorist attack. A shot from a modern rifle anywhere along the 350-mile Hyperloop could theoretically pierce the thin steel exterior of the tube and destroy the entire system. The issue surrounding the design is that it is virtually impossible to defend against any attack such as this. As long as the Hyperloop is exposed, it is susceptible to this type of risk.

2. Power outages

Another external risk factor associated with the design of the Hyperloop is the issue presented by a potential power outage. Although this would be unlikely, if a power outage were to occur mid-operation, the linear accelerators used to safely decelerate each capsule would be ineffective. This would serve as a huge risk, as the capsules would not be able to come to a complete stop before reaching the destination. Thus, engineers were forced to design a fail-safe system to eliminate this risk. The proposed design of the Hyperloop features a battery storage system equipped to each linear accelerator. In the event of a power outage, these backup energy storage systems kick in and provide each linear accelerator with the sufficient power required for safe capsule deceleration. In addition, each capsule is also equipped with a fail-safe mechanical breaking system that could be automatically triggered in the event of an emergency.

3. Earthquakes

Another key external risk factor surrounding the Hyperloop is the potential for an earthquake. In fact, the state of California averaged over 250 annual earthquakes—considering only those above 3 on the Richter scale—between the periods of 2010 to
2015. Therefore, earthquakes are relatively common and pose a significant threat to the Hyperloop, as a large enough earthquake could damage the pylons that serve as the foundation for the tubes. Thus, engineers are forced to incorporate a dampening mechanism into the design. The proposed strategy will integrate two adjustable lateral dampers and one vertical damper into each pylon in order to reduce the risk associated with any type of ground movement, such as during an earthquake. This plan would likely be effective for dampening the vibration experienced during mild-magnitude earthquakes, but would not eliminate all of the risk associated with larger, more destructive earthquakes—which are particularly prevalent in California.

Figure 11. California seismic hazard map
The figure, shown above, displays the Seismic Hazard Map for the state of California provided by the United States Geological Survey in 2008. The map exhibits the variable level of earthquake risk across the entire region. The regions denoted in red pose the highest risk, whereas, the regions denoted in green pose less of a risk. Through observation, it is apparent that the proposed Hyperloop route between San Francisco and Los Angeles would fall directly within the highest-risk region, thus threatening the sustainability of the Hyperloop.

**Legal Issues**

1. **Obtaining land use rights**

   As explained before, it is essential for the Hyperloop route to limit any curvature in order to minimize the uncomfortable inertial acceleration effects experienced by passengers. Although the proposed San Francisco to Los Angeles Hyperloop route would predominantly follow alongside the California Interstate 5 highway on publicly owned property, sections of the tube would be forced to deviate from the path when the freeway featured sharp turns. This presents a potential setback. As much of the land surrounding the Interstate is privately owned, the design team would be faced with numerous legal issues associated with obtaining private land use rights. Private landowners would likely attempt to negotiate sizable monetary compensation in return for their permission, which would allow the Hyperloop to occupy portions of their land. Thus, obtaining these rights would likely be time-consuming and expensive, adding additional costs to the total budget.
2. Environmental pushback

Just as there would be pushback from private landowners, there would also likely be pushback from environmental activists. Conservational opponents could argue that the construction of the Hyperloop would disrupt the natural environment and damage ecological systems in the surrounding regions. Overtime, this could surmount to additional lobbyist fees and increased regulation that would hinder the construction of the Hyperloop.
Chapter 3
Potential Markets

There are two potential markets that exist for the Hyperloop system—human passengers and freight. Although the remainder of this paper concentrates solely on the passenger market, this chapter will compare both potential markets, highlighting the advantages and disadvantages associated with each. This section will also provide an overview of several alternative Hyperloop routes that are currently being considered.

Freight vs. Passengers

As discussed in Chapter 2, Hyperloop One plans to be “moving cargo by 2020 and passengers by 2021.” The rationality behind this decision—to focus on freight before human passengers—stems from the plethora of safety concerns surrounding the technology. The idea is that once Hyperloop cargo routes have been implemented successfully, the technology will become more familiar to consumers, causing their negative perceptions to shift. Therefore, the freight routes will essentially serve as a proof-of-concept by validating to consumers that the technology is safe and can be trusted.

Aside from confirming the proof-of-concept, there are several advantages to implementing Hyperloop freight routes over traditional passenger routes. Since freight routes would not be transporting humans, the risk of human fatalities caused by a catastrophic event,
such as a terrorist attack, would be dramatically reduced. Additionally, the air pressure and amount of oxygen in the capsule would also be less of a concern, since cargo would not demand as stringent of atmospheric requirements as humans do. Therefore, any capsule depressurization during transit would not have as severe of consequences as in the case of a passenger route. One of the main concerns with the passenger version of the Hyperloop is the negative inertial effect likely to cause discomfort to passengers traveling along slight curves at transonic speeds. An advantage of the freight version is that cargo would not be affected by discomfort and could be securely stowed so as to eliminate any damage that would be caused by these inertial forces. Since cargo routes would not be as limited by strict curvature requirements, engineers could instead focus on designing routes that would be more cost effective than passenger routes. Another benefit of Hyperloop freight routes is that they could be operated around the clock, whereas, passenger routes would likely experience a more sporadic distribution of utilization during peak hours versus off-hours. Assuming that pricing was relatively consistent between both versions of the Hyperloop, this potential for higher utilization would translate to the freight routes generating more revenue.

In comparing both prospective versions of the Hyperloop, there are several drawbacks to the freight model. To begin, the design of the freight version would be significantly larger and weigh more than the passenger version. The table below compares the estimated dimensions and weight of each design.
As shown above, the design of the freight capsule would be roughly 73% heavier than the passenger capsule when fully loaded. This additional weight would mean that more energy would be required to propel the freight capsule through the system. Thus, the freight version would be less energy-efficient than the passenger version. This extra weight would also put more strain on the system and likely require more pylons to support the heavier freight capsules and tubes. With this larger and heavier freight model, there would be additional construction costs incurred—from the extra pylons required to the stronger suspension system. The table below compares some of the estimated costs associated with each design.

**Table 2. Dimension and Weight Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Passenger Capsule</th>
<th>Freight Capsule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal surface area</td>
<td>15 ft²</td>
<td>43 ft²</td>
</tr>
<tr>
<td>Interior tube diameter</td>
<td>7 ft 4 in</td>
<td>10 ft 10 in</td>
</tr>
<tr>
<td>Structure weight</td>
<td>6,800 lb</td>
<td>7,700 lb</td>
</tr>
<tr>
<td>Interior weight</td>
<td>5,500 lb</td>
<td>6,000 lb</td>
</tr>
<tr>
<td>Air bearing system weight</td>
<td>6,200 lb</td>
<td>8,400 lb</td>
</tr>
<tr>
<td>Propulsion system weight</td>
<td>2,900 lb</td>
<td>3,500 lb</td>
</tr>
<tr>
<td>Battery system weight</td>
<td>5,500 lb</td>
<td>12,100 lb</td>
</tr>
<tr>
<td>Total estimated weight</td>
<td>33,000 lb</td>
<td>57,000 lb</td>
</tr>
</tbody>
</table>

(when fully stocked)

**Table 3. Cost Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Passenger Version</th>
<th>Freight Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capsule structure cost</td>
<td>$245,000</td>
<td>$275,000</td>
</tr>
<tr>
<td>Capsule interior cost</td>
<td>$255,000</td>
<td>$185,000</td>
</tr>
<tr>
<td>Suspension system cost</td>
<td>$475,000</td>
<td>$565,000</td>
</tr>
<tr>
<td>Battery/motor/electronics system cost</td>
<td>$150,000</td>
<td>$200,000</td>
</tr>
<tr>
<td>Propulsion system cost</td>
<td>$125,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>Hyperloop tube cost</td>
<td>$650,000,000</td>
<td>$1,200,000,000</td>
</tr>
<tr>
<td>Pylon &amp; tube joints cost</td>
<td>$2,550,000,000</td>
<td>$3,150,000,000</td>
</tr>
</tbody>
</table>
Aside from the increased upfront and operational costs associated with the freight model, another important thing to consider is the recent trend in the freight transportation industry. Since 2012, the average capacity utilization throughout the airfreight industry has decreased to 43.5%, as a result of larger commercial passenger fleets absorbing much of the cargo shipment demand.\textsuperscript{29} In turn, this has led to a decrease in the cost of airfreight transportation. This is important to note, as the Hyperloop freight model would directly compete with the airfreight industry. If these prices continue to fall, it would be tough for the Hyperloop freight system to offer competitive services while operating profitably.

**Prospective Routes**

**Jakarta to Yogyakarta, Indonesia**

![Figure 12. Proposed route from Jakarta to Yogyakarta, Indonesia\textsuperscript{24}](image)

The proposed route between Jakarta and Yogyakarta, Indonesia would be approximately 330 miles in length.\textsuperscript{17} Currently, the existing modes of transportation between these two major
cities are by plane, train, and automobile. On average, the flight time between Jakarta and Yogyakarta is about 70 minutes, express trains take from 7.5 – 9.5 hours, and travel by car takes about 11.5 hours. In comparison, the Hyperloop route from Jakarta to Yogyakarta would take approximately 25 minutes—roughly 35% of the total travel time required for the next fastest mode of transportation. Hyperloop Transportation Technologies is also exploring potential routes to Bandung and another from Jakarta Soekarno-Hatta International Airport to the Jakarta city center, which would have a travel time of roughly 9 and 5 minutes respectively. The passenger market in this region is massive. Indonesia is the fourth most populated country in the world, with a population of over 260 million people. Jakarta alone has over 10 million residents and is particularly known for its severe traffic congestion that makes the daily commute unbearable for citizens. In addition, air pollution derived from automobile emissions has become a real issue in this region of Indonesia. Thus, the Hyperloop would be an ideal solution for alleviating traffic congestion and air pollution problems currently faced in Jakarta.

**Abu Dhabi to Dubai, United Arab Emirates**

![Abu Dhabi to Dubai Route](image)

*Figure 13. Proposed route from Abu Dhabi to Dubai, United Arab Emirates*
The proposed route between Abu Dhabi to Dubai, United Arab Emirates would be approximately 100 miles in length. Currently, the only existing mode of transportation between these two major cities is by car or bus. On average, the drive from Abu Dhabi to Dubai takes about 2 hours, but can exceed 3 hours if public transportation is used. Traffic is also a significant problem in this region and can lead to even longer transportation times between these cities. In comparison, the Hyperloop route from Abu Dhabi to Dubai would take about 12 minutes—roughly 10% of the total travel time required for the next fastest mode of transportation. On November 8, 2016, Hyperloop One announced that they had signed an agreement with the Dubai Roads and Transport Authority to conduct an initial feasibility report for the design of the Hyperloop route connecting Abu Dhabi to Dubai. Hyperloop One also partnered with McKinsey & Co. and the Bjarke Ingels Group (BIG) to support this preliminary study. Along the proposed route, shown above, the Hyperloop would connect three major airports—Abu Dhabi Airport, Dubai Airport, and Al Maktoum Airport. In addition, Hyperloop One is exploring the possibility of freight routes that would connect two of the largest cargo ports in the UAE—Jebel Ali Port and Khalifa Port. Shervin Pishevar, executive chairman at Hyperloop One, explained the potential impact that the cargo route would have in this region, “The port system means unloading can happen offshore and the tube can unload the load in the desert. It gets trucks off the roads. You can unlock billions of dollars of waterfront property for redevelopment.”
Prague to Brno, Czech Republic to Bratislava, Slovakia

Figure 14. Proposed route from Prague to Brno, Czech Republic to Bratislava, Slovakia\(^7\)

Brno, Czzech Rep. to The entire route from Prague to Brno, Czech Republic and from Brno to Bratislava, Slovakia would be approximately 220 miles in length.\(^{17}\) Currently, the existing modes of transportation between these three major cities are by train and car. From Prague to Brno, it takes roughly 2.5 hours to drive and about 3 hours by train.\(^7\) Between Brno and Bratislava, it takes about 1.5 hours to either drive or take a train. In comparison, the Hyperloop route from Prague to Brno would take approximately 17 minutes—roughly 11% of the total travel time required for the next fastest mode of transportation. Likewise, the Hyperloop route from Brno to Bratislava would take approximately 10 minutes, which is also about 11% of the total travel time required for the next fastest mode of transportation.\(^{17}\)
Chapter 4

Alternative Modes of Transportation

When analyzing the feasibility of implementing Hyperloop technology, it is important to consider the alternative forms of transportation that currently exist. This section will focus on comparing how various modes of modern transportation, including automobiles, commercial jets, Maglev trains, and the proposed California High Speed Rail, would stack up along the proposed San Francisco to Los Angeles route. In order to standardize the evaluation, each form of transportation will be assessed by the same criteria. The table below demonstrates the comparison between the Hyperloop and four alternative modes of transportation.

Table 4. Hyperloop Comparison to Alternative Modes²

<table>
<thead>
<tr>
<th>Mode of Transportation</th>
<th>Automobile</th>
<th>Commercial Jet</th>
<th>Maglev Train</th>
<th>California High Speed Rail</th>
<th>Hyperloop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed (miles/hour)</td>
<td>70 mph</td>
<td>600 mph</td>
<td>250 mph</td>
<td>164 mph</td>
<td>600 mph</td>
</tr>
<tr>
<td>Maximum speed (miles/hour)</td>
<td>268 mph</td>
<td>700 mph</td>
<td>375 mph</td>
<td>220 mph</td>
<td>760 mph</td>
</tr>
<tr>
<td>Travel time (minutes)</td>
<td>330 mins</td>
<td>75 mins</td>
<td>84 mins</td>
<td>158 mins</td>
<td>35 mins</td>
</tr>
<tr>
<td>Passenger capacity (passengers per vehicle)</td>
<td>8 per car</td>
<td>300 per flight</td>
<td>1200 per train</td>
<td>450+ per train</td>
<td>28 per capsule</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Flexible routine, random stop</td>
<td>Fixed routine, non-stop</td>
<td>Fixed Routine, frequent stop</td>
<td>Fixed Routine, frequent stop</td>
<td>Fixed Routine, frequent stop</td>
</tr>
<tr>
<td>Energy per passenger per journey (Mega Joules)</td>
<td>~800 MJ</td>
<td>~1020 MJ</td>
<td>~120 MJ</td>
<td>~840 MJ</td>
<td>~45 MJ</td>
</tr>
<tr>
<td>CO2 emission per passenger per journey (lbs)</td>
<td>~185 lbs</td>
<td>~217 lbs</td>
<td>~171.5 lbs</td>
<td>~91 lbs</td>
<td>~0 lbs</td>
</tr>
<tr>
<td>Sustainably self-powering?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Immune to weather?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Resistant to earthquakes?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Station size</td>
<td>N/A</td>
<td>Large</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Implementation costs (USD)</td>
<td>N/A</td>
<td>N/A</td>
<td>~ $50 - 90 billion</td>
<td>~ $68.4 billion</td>
<td>~ $6 - 35 billion</td>
</tr>
<tr>
<td>Average one-way cost per passenger (USD)</td>
<td>$90</td>
<td>$150</td>
<td>N/A</td>
<td>$105</td>
<td>$31 - $67</td>
</tr>
</tbody>
</table>
Benefits of the Hyperloop

1. Fastest Speed

The average operational speed of the Hyperloop would be 600 mph, and the maximum speed would be 760 mph. This is the fastest mode of transportation under consideration, but is relatively comparable to the commercial jet.

2. Shortest Travel Time

The Hyperloop would support the shortest travel time along the San Francisco to Los Angeles route at an estimated travel time of 35 minutes. This is just 46% of the total travel time required for the next fastest mode of travel—the commercial jet.

3. Most Energy Efficient

The Hyperloop is the most energy efficient mode of transportation under consideration, requiring only 45 mega joules of energy per passenger per journey. This is significantly more energy efficient than the Maglev train, which is the next most energy efficient mode of travel.

4. Zero Carbon Dioxide Emissions

The Hyperloop is also the cleanest mode of transportation under consideration, as it is the only form that produces no carbon dioxide emissions.

5. Self-Sustainable

The Hyperloop is the only mode of transportation under consideration that is sustainably self-powering. The Hyperloop will take advantage of its solar array design to, in some cases, even generate a surplus of power that can be sold back to the grid.
6. Immunity to Weather

The Hyperloop is a closed system, and is, thus, immune to the effects of weather. This is one of the major advantages that the Hyperloop has over commercial airline travel.

7. Resistance to Earthquakes

The Hyperloop is the only mode of rail transportation that is resistant to earthquakes. It takes advantage of the pylon and dampening system design to support this feature, which is especially important along the earthquake-prone San Francisco to Los Angeles route.

8. Lowest Implementation Costs

The Hyperloop is expected to cost between 6 and 35 billion dollars to construct, making it the mode of transportation associated with the lowest implementation costs. This is significantly cheaper than the proposed California High Speed Rail, which is expected to cost over $68 billion.23

9. Cheapest Ticket Price

The Hyperloop would be the cheapest mode of transportation along the proposed route—with an average one-way ticket price ranging from $31 to $67. This is considerably less expensive than the average price of travelling via an automobile, which is the next cheapest mode of transportation.
Chapter 5

Potential Revenue Analysis

The first step in our valuation of the Hyperloop concept was to analyze the potential revenue of the proposed San Francisco to Los Angeles route. In order to forecast the expected revenue of the Hyperloop over the next two decades, we had to estimate the annual consumer demand of the system, determine appropriate growth rates, and create a ticket-pricing model to evaluate the potential revenue that would be produced at various price levels. This section will describe each of these steps in depth and explain several of the assumptions that were built into the Hyperloop revenue model.

Estimated Consumer Demand Forecast

In order to estimate the potential revenue that the San Francisco to Los Angeles Hyperloop route would generate, it was necessary to gauge the expected consumer demand of the system. The first step was to determine the total volume of passenger travel between San Francisco and Los Angeles in 2016, which was set as the base year for our model. Currently, the only two modes of transportation between the city-pair are by airplane or car travel, and thus, these were the only two markets considered in our analysis. From the Domestic Airline Consumer Airfare Report posted on the US Department of Transportation website, we found the
total amount of airline passengers that traveled between the San Francisco and Los Angeles city-pair market to be roughly 7.44 million passengers in 2016.\textsuperscript{8}

In the five years prior to 2016, between 2011-2015, the average annual growth rate was 2.11\% for the passenger demand between these two cities. For simplification of our model, we applied a standard 2\% growth rate to forecast the annual consumer airline demand from 2016 out to year 2035. These demand forecasts are listed in the Appendix section. The next step was to estimate the amount of passengers that travel by car between the two cities each year. This step was not as simple as the last, as there was a lack of available information that would indicate an exact number. We determined that the best technique for this approximation was to follow a similar methodology used in a 2013 University of Chicago report\textsuperscript{13}, which derived the quantity of car travelers from airline passenger data. From examination of the Domestic Travel Market Report produced by the U.S. Travel Association, we calculated the ratio of domestic travel between airlines and car travel to be 28\% and 72\% respectively.\textsuperscript{21} Assuming that this rough breakdown would remain constant throughout our forecast horizon, we applied this ratio to the consumer airline demand forecasts (calculated in the previous step) to back into the forecast for car travel demand between the two cities. With airline demand and car travel demand successfully forecasted, we simply added both components to determine the forecasted values for the total volume of passenger travel between San Francisco and Los Angeles.

\begin{table}[h]
\centering
\begin{tabular}{lcccc}
\hline
 & 2017 & 2020 & 2025 & 2030 & 2035 \\
\hline
Annual Airline Demand & 7,595,472.31 & 8,060,375.98 & 8,899,306.39 & 9,825,553.35 & 10,848,204.83 \\
Annual Car Travelers & 19,531,215 & 20,726,681 & 22,883,931 & 25,265,709 & 27,895,384 \\
Total Annual Demand & 27,126,686.83 & 28,877,057.08 & 31,783,237.10 & 35,091,261.95 & 38,743,588.68 \\
\hline
\end{tabular}
\caption{Annual Demand Forecasted to 2035, Travel}
\end{table}
The table above shows the forecasted annual demand between San Francisco to Los Angeles between 2017 and 2035. It is important to note that this annual demand is probably underestimated, as the Hyperloop would likely draw large crowds due to its revolutionary nature and ability to open up opportunities for efficient travel that were not previously available. From this annual demand forecast, we were able to compare these values to the capacity of the proposed Hyperloop system to derive ridership estimates for the San Francisco to Los Angeles route over the next two decades. In order to make this comparison, we first had to calculate the annual capacity of the proposed system:

\[
28 \text{ (passengers per capsule)} \times 720 \text{ (departures/day)} \times 365 \text{ (days)} \times 2 \text{ (tubes)}
\]

\[= 14.72 \text{ million annual passengers}\]

For this calculation, we assumed that each 28-person capsule departed every 2 minutes on average, totaling 720 departures per day. Since the forecasted annual demand exceeded the annual capacity of the system, we concluded that the system would theoretically be at constant capacity. For our valuation, however, we applied a utilization multiple to account for realistic scenarios in which each capsule was not filled to capacity, as is common within the consumer airline industry.

**Estimated Ticket Pricing**

The next step in estimating the potential revenue was to create a ticket-pricing model. To begin, we calculated the current weighted average cost of travel between San Francisco to Los Angeles in 2016, based on the average cost of airline and car travel. From the Domestic Airline
Consumer Airfare Report, we found the average airline ticket price between San Francisco and Los Angeles to be $149.57 in 2016.\(^{21}\) In order to find the average cost of car travel between the two cities, we referred to average gas prices listed by AAA. In 2016, the average price of gas in California was about $3.00/gallon, or $0.10/mile assuming the average 30-mpg car.\(^1\) Thus, the average cost of car travel along the 350-mile route between San Francisco and Los Angeles was roughly $35.00 (350 miles x $0.10/mile). After estimating the average cost of airline and car travel, we calculated the weighted average cost of travel between San Francisco to Los Angeles:

\[
(0.28 \times $149.57) + (0.72 \times $35.00) = $67.08
\]

To simplify our model, we used $67.00 as the weighted average cost of travel for one of the ticket price options. Since the revenue analysis would be drastically influenced by the estimated ticket price of the Hyperloop system, we wanted to the model under various ticket price assumptions. Several feasibility studies conducted by third party firms recommended a ticket price in the mid-20 to mid-30 dollar range, in order for the Hyperloop to operate profitably. Furthermore, in the initial Hyperloop white papers, the suggested ticket price for the San Francisco to Los Angeles route was $20 plus operational costs.\(^{23}\) The next section will explain the estimated operational costs of the system in depth, but for the purpose of ticket pricing, this suggested price would come out to roughly $31, in order to cover the operating costs associated with each passenger. We used this $31 proposed ticket price as the least expensive scenario to analyze. In order to create a base ticket price, we took the mid-point of the weighted average cost of transportation ($67) and the proposed ticket price ($31), which was $49. The table below exhibits the three ticket price assumptions that we applied to our revenue model.
Table 6. Ticket Price Assumptions

<table>
<thead>
<tr>
<th>Ticket Price</th>
<th>$49.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>$67.00 WACT</td>
<td></td>
</tr>
<tr>
<td>$49.00 Base</td>
<td></td>
</tr>
<tr>
<td>$31.00 Proposed</td>
<td></td>
</tr>
</tbody>
</table>

Revenue Model

In order to forecast up until 2035, we applied a modest 2.5% annual growth rate to the ticket price, which would likely ensure that the ticket price would continue to grow on an inflation-adjusted basis. The next step in our revenue projection was to multiply the forecasted annual passengers by the ticket price to determine the total annual passenger income of the Hyperloop route. As described earlier, we determined that the annual demand would surpass the capacity of the system, meaning that the system would theoretically operate at constant capacity. However, it would be unrealistic to assume that every capsule that left the Hyperloop station each year would be completely full. Therefore, we applied a realistic 90% capacity utilization multiple to the Hyperloop annual capacity to estimate the amount of annual passengers who would use the system. Since additional revenue would be generated from selling any excess solar power, this was important to include in our model. We used the $25 million estimated value that was listed in the white papers as the basis for the excess energy income section of our revenue model. The final step was to add the excess energy income to the passenger income to determine the estimated total revenue of the Hyperloop route. The table below outlines the
projected revenue estimates for the base-case scenario—under the 90% capacity utilization and $49 ticket-price assumptions.

Table 7. Hyperloop Revenue Model, Condensed

<table>
<thead>
<tr>
<th>Revenue Estimation</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Passengers</td>
<td>13,245,120</td>
<td>13,245,120</td>
<td>13,245,120</td>
<td>13,245,120</td>
</tr>
<tr>
<td>Passenger-Miles</td>
<td>4,635,792,000</td>
<td>4,635,792,000</td>
<td>4,635,792,000</td>
<td>4,635,792,000</td>
</tr>
<tr>
<td>Ticket Price</td>
<td>$49.00</td>
<td>$55.44</td>
<td>$62.72</td>
<td>$70.97</td>
</tr>
<tr>
<td>Passenger Income</td>
<td>$649,010,880</td>
<td>$734,296,240</td>
<td>$830,788,797</td>
<td>$939,961,268</td>
</tr>
<tr>
<td>Excess Energy Income</td>
<td>$25,000,000</td>
<td>$25,000,000</td>
<td>$25,000,000</td>
<td>$25,000,000</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td><strong>$674,010,880</strong></td>
<td><strong>$759,296,240</strong></td>
<td><strong>$855,788,797</strong></td>
<td><strong>$964,961,268</strong></td>
</tr>
</tbody>
</table>
Chapter 6

Estimated Cost Analysis

The next step in our valuation of the Hyperloop concept was to analyze the potential costs associated with the proposed San Francisco to Los Angeles route. For our valuation, we focused on determining if the Hyperloop system would be operationally profitable first, by initially disregarding the cost of implementation. Once we estimated the operational profitability, we could start to consider how the implementation costs could be covered by the future flow of operational income. In order to forecast the expected operational costs of the system over the next two decades, we divided the costs into two categories—variable operating costs and fixed maintenance costs. Once both of these costs were estimated, we created a model to evaluate the operating profit produced at various cost levels. This section will describe each of these steps in depth, explain several of the assumptions that were built into the operational cost model, and provide a high-level outline for the estimated total implementation costs of the Hyperloop system.

Estimated Fixed Maintenance Cost Forecast

In order to estimate the operational costs that would be incurred by the San Francisco to Los Angeles Hyperloop route, it was necessary to first forecast the fixed maintenance cost. We defined the fixed costs of the Hyperloop as any cost that was associated with the maintenance of
the system, including the cost of labor, energy, or materials required for upkeep. The fixed maintenance cost was expressed in terms of dollars per mile. Since the Hyperloop system has not been implemented yet, it was difficult to gauge this value. As a foundation for this analysis we looked at a 2016 feasibility analysis conducted by KPMG, which estimated the annual fixed cost of maintenance for the proposed Helsinki to Stockholm Hyperloop route to be $137,761 per mile. With not much else to base this cost estimate off of, we set $140,000 as the base-case scenario for our operational cost model. In order to create a dynamic model that could evaluate the operational profitability at various cost levels, we considered two other fixed cost structures. The table below exhibits the three fixed cost assumptions that we applied to our operational cost model.

<table>
<thead>
<tr>
<th>Fixed Cost (per mile)</th>
<th>Optimistic</th>
<th>Base</th>
<th>Worse-case</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$140,000</td>
<td>Optimistic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$180,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Estimated Variable Operating Cost Forecast

The next step was to estimate the variable operating costs of the proposed route. We defined the variable operating costs as any cost that was associated with the operation of the system, including labor, energy, selling, general, and administrative costs. The variable operating cost was expressed in terms of dollars per passenger-mile. As explained in the previous subsection, since the Hyperloop system has not been implemented yet, it was difficult to gauge this value. Again, we referred to the 2016 KPMG study as the basis for this estimate. According to KPMG, the variable operating costs for the Helsinki-Stockholm route would be
roughly $0.02 per passenger-mile. Therefore, we set this value as the base-case scenario for our operational cost model. As the operational profitability would be highly sensitive to this value, we also considered two alternative variable cost structures in our analysis of the potential cost. The table below exhibits the three variable cost assumptions that we applied to our operational cost model.

<table>
<thead>
<tr>
<th>Variable Cost (per passenger mile)</th>
<th>$0.020</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.015 Optimistic</td>
<td></td>
</tr>
<tr>
<td>$0.020 Base</td>
<td></td>
</tr>
<tr>
<td>$0.025 Worse-case</td>
<td></td>
</tr>
</tbody>
</table>

**Table 9. Variable Costs**

The next step in our cost projection was to calculate the annual fixed maintenance costs and variable operating costs by multiplying these (per mile and per passenger-mile) values by the total trip length and annual passenger-miles, respectively. In order to forecast up until 2035, we applied a 2% annual growth rate to both the variable operating and fixed maintenance costs, which is in line with the current rate of inflation. The final step was to add both of these annual costs to determine the estimated total operational cost of the Hyperloop route. The table below outlines the projected operational cost estimates for the base-case scenario—under the $140,000 per mile fixed cost and $0.02 per passenger-mile variable cost assumptions.
**Table 10. Operating Cost Estimates**

<table>
<thead>
<tr>
<th>Operational Cost Estimation</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Operating Costs</td>
<td>$92,715,840</td>
<td>$102,365,779</td>
<td>$113,020,092</td>
<td>$124,783,314</td>
</tr>
<tr>
<td>Fixed Maintenance Costs</td>
<td>$49,000,000</td>
<td>$54,099,959</td>
<td>$59,730,727</td>
<td>$65,947,549</td>
</tr>
<tr>
<td>Total V&amp;F Costs</td>
<td>$141,715,840</td>
<td>$156,465,738</td>
<td>$172,750,818</td>
<td>$190,730,862</td>
</tr>
<tr>
<td>Operating Profit</td>
<td>$507,295,040</td>
<td>$577,830,501</td>
<td>$658,037,978</td>
<td>$749,230,405</td>
</tr>
</tbody>
</table>

The operating profit, shown at the bottom of the table, was calculated by subtracting the operational cost estimates from the revenue estimates (forecasted in the previous section). Under this base-case scenario, it is clear that the Hyperloop system would be operationally profitable from the beginning, returning over a half-billion dollars in the first year alone. If our assumptions were correct, the profitability of the proposed Hyperloop system would continue to increase throughout our forecast horizon, ultimately returning almost three-quarters of a billion dollars in profit in 2035.

**Estimated Implementation Costs**

So far, we have just focused on the operational costs incurred annually to determine the operational profitability—under the assumption that the system had already been successfully built. The other cost component that is critical to evaluate is the cost of implementation. In other words, how much would the initial investment be to build the Hyperloop route between San Francisco to Los Angeles? Fortunately, much of these implementation costs were outlined in the Hyperloop white papers. The table below summarizes the total cost of the Hyperloop transportation system as described in the 2013 white papers.
According to this estimate, the total implementation costs of the proposed Hyperloop route would be about $6 billion or $17.14 million per mile.\textsuperscript{23} This cost estimate, however, has drawn a ton of criticism over the past few years. A variety of reputable sources have since claimed that this $6 billion price tag is a dramatic underestimation of what the actual implementation costs would be. In fact, KPMG estimated the total cost of the Helsinki-Stockholm route to be roughly $64 million per mile—over three times the cost of the initial white papers estimate.\textsuperscript{25} Additionally, other estimates have come in at even higher per-mile costs. In 2016, Hyperloop One estimated the per-mile costs of the Hyperloop system to be in the range of $84 - $121 million per mile.\textsuperscript{19} Therefore, per-mile cost estimates for the Hyperloop system vary significantly across the board and are largely influenced by the particular region in which the system would be implemented. In order to conduct a dynamic analysis that would interpret a wide range of estimates, we decided to consider the implications of three cost-based

\begin{table}[h]
\centering
\caption{Implementation Cost Estimates, White Papers\textsuperscript{23}}
\begin{tabular}{|l|c|}
\hline
Component & Cost (million USD) \\
\hline
\hline
Capsule & 54 (40 capsules) \\
\hline
Capsule Structure \& Doors & 9.8 \\
Interior \& Seats & 10.2 \\
Compressor \& Plumbing & 11 \\
Batteries \& Electronics & 6 \\
Propulsion & 5 \\
Suspension \& Air Bearings & 8 \\
Components Assembly & 4 \\
\hline
Tube & 5,410 \\
Tube Construction & 650 \\
Pylon Construction & 2,550 \\
Tunnel Construction & 600 \\
Propulsion & 140 \\
Solar Panels \& Batteries & 210 \\
Station \& Vacuum Pumps & 260 \\
Permits \& Land & 1,000 \\
\hline
Cost Margin & 536 \\
\hline
Total & 6,000 \\
\hline
\end{tabular}
\end{table}
scenarios. The table below exhibits the three implementation cost assumptions that we considered in our analysis.

<table>
<thead>
<tr>
<th>Implementation Cost Estimates (in millions USD)</th>
<th>Assumption Type</th>
<th>Source</th>
<th>Per-Mile (in millions USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$6,000</td>
<td>Very Optimistic</td>
<td>White papers</td>
<td>$17</td>
</tr>
<tr>
<td><strong>$22,400</strong></td>
<td><strong>Base</strong></td>
<td><strong>KPMG study</strong></td>
<td><strong>$64</strong></td>
</tr>
<tr>
<td>$35,000</td>
<td>Worse-case</td>
<td>Hyperloop One</td>
<td>$100</td>
</tr>
</tbody>
</table>

Under the base-case scenario, the cost of implementation is $64 million per mile, which leads to a total implementation cost of $22.4 billion for the proposed San Francisco to Los Angeles route. We believe that this is a more accurate representation of what the total cost for building the Hyperloop system would be, as opposed to the $6 billion price tag that was optimistically derived in the initial white papers.
Chapter 7

Hyperloop Valuation

Once the potential revenue and operational costs were estimated and forecasted through 2035, the next step in our Hyperloop valuation was to create a discounted cash flow model. For our DCF valuation, the projection period was between 2020 and 2035. In simplifying our model, this projection period assumes that by 2020, the Hyperloop route between San Francisco to Los Angeles has been completed and is fully operational. Admittedly, this is an optimistic approximation given the complexity of the project, but this assumption merely serves as a basis for the projection period. In other words, our (3-year) length of construction period assumption does not influence the operational profitability or total project value of the system. Changes in the duration assumption would simply shift the whole projection period. To begin our DCF analysis, we took the operating income projections (calculated in the previous section) from 2020 to 2035 and discounted them back to the present value using an appropriate discount rate. For the purpose of our dynamic analysis, we chose two different values for the weighted average cost of capital to be used as the discount rate. The table below shows the two discount rates that were considered in our study.

Table 13. Discount Rate Assumptions
The first discount rate that we used was 7%. This value was appropriate; as it represented the private sector opportunity return rate (not including any risk premium), as well as the discount rate used in the proposed California High Speed Rail project. The second discount rate that we used in our analysis was 11%. This larger value was also appropriate, as it adjusted the 7% rate by the risk premium over the private sector opportunity return rate, which would be critical to compensate for the risk associated with an investment in the Hyperloop. The 11% discount rate is likely more realistic, as it represents the rate that debt or equity investors would expect to return from this type of risky investment. Therefore, we set 11% as the base-case discount rate to be used in our DCF valuation.

To incorporate forecasted operating income from years outside of our projection period, we used the perpetuity growth method in our valuation. For this step, we took the operating income from 2035 and applied a perpetuity growth rate of 3% to estimate the present value of the terminal value. Our 3% base-case perpetuity growth rate is in line with the expected annual US GDP growth rate. Furthermore, we can also evaluate the change in the output of the present terminal value when alternative perpetuity growth rates are considered, such as those described in the table below.

<table>
<thead>
<tr>
<th>Perpetuity Growth Rate</th>
<th>4% Optimistic</th>
<th>3% Base</th>
<th>2% Worse-case</th>
</tr>
</thead>
</table>

Once the present values of the forecasted operating income and the terminal value were calculated, we added these values to determine the total present value of operating income for the
proposed Hyperloop route. The table below demonstrates the calculation for the total present value of the operating income, under the base-case scenario—with 11% discount rate and 3% perpetuity growth rate assumption. In this base case, the present value of operating income was roughly $12.7 billion.

Table 15. DCF Valuation Model, Condensed

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Income</td>
<td>$507,295,040</td>
<td>$577,830,501</td>
<td>$658,037,978</td>
<td>$749,230,405</td>
</tr>
<tr>
<td>Year</td>
<td>4</td>
<td>9</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>PV of Income</td>
<td>$334,170,956</td>
<td>$225,888,257</td>
<td>$152,661,405</td>
<td>N/A</td>
</tr>
<tr>
<td>Sum of Operating Income PV</td>
<td></td>
<td></td>
<td></td>
<td>$3,065,507,716</td>
</tr>
<tr>
<td>PV of Terminal Value</td>
<td></td>
<td></td>
<td></td>
<td>$9,646,341,470</td>
</tr>
<tr>
<td>Total PV of Operating Income</td>
<td></td>
<td></td>
<td></td>
<td>$12,711,849,186</td>
</tr>
</tbody>
</table>

Sensitivity Analysis

Due to the ambiguous nature of this project, it is important to evaluate the effects that certain variables will have on the system. In order to analyze the operational profitability of the proposed Hyperloop route, we will determine the impact that varying ticket price, variable cost, and discount rate assumptions have on the model. Our sensitivity analysis will consider the following 9 scenarios listed in the table below.

Table 16. Scenarios for Sensitivity Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low value, Low value</td>
</tr>
<tr>
<td>2</td>
<td>Low value, Base value</td>
</tr>
<tr>
<td>3</td>
<td>Low value, High value</td>
</tr>
<tr>
<td>4</td>
<td>Base value, Low value</td>
</tr>
<tr>
<td>5</td>
<td>Base value, Base value</td>
</tr>
<tr>
<td>6</td>
<td>Base value, High value</td>
</tr>
<tr>
<td>7</td>
<td>High value, Low value</td>
</tr>
<tr>
<td>8</td>
<td>High value, Base value</td>
</tr>
<tr>
<td>9</td>
<td>High value, High value</td>
</tr>
</tbody>
</table>
For example, in scenario 1, the ticket price is $31.00 and the variable operating cost is $0.015 per passenger-mile. The table below shows the results of our DCF analysis under each of the 9 scenarios and compares the results from both discount rate assumptions.

**Table 17. Sensitivity Analysis Results**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Implementation Costs (in billions USD)</th>
<th>Present Value (in billions)</th>
<th>Percent Financeable</th>
<th>Present Value (in billions)</th>
<th>Percent Financeable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Discount Rate: 7%</td>
<td></td>
<td></td>
<td>Discount Rate: 11%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$22.4 - $35.0</td>
<td>$13.75</td>
<td>39 - 61%</td>
<td>$7.37</td>
<td>21 - 33%</td>
</tr>
<tr>
<td>2</td>
<td>$22.4 - $35.0</td>
<td>$12.75</td>
<td>36 - 57%</td>
<td>$6.84</td>
<td>20 - 31%</td>
</tr>
<tr>
<td>3</td>
<td>$22.4 - $35.0</td>
<td>$11.76</td>
<td>34 - 52%</td>
<td>$6.30</td>
<td>18 - 28%</td>
</tr>
<tr>
<td>4</td>
<td>$22.4 - $35.0</td>
<td>$24.70</td>
<td>71 - 100%</td>
<td>$13.25</td>
<td>38 - 59%</td>
</tr>
<tr>
<td>5</td>
<td>$22.4 - $35.0</td>
<td>$23.70</td>
<td>68 - 100%</td>
<td>$12.71</td>
<td>36 - 57%</td>
</tr>
<tr>
<td>6</td>
<td>$22.4 - $35.0</td>
<td>$22.70</td>
<td>65 - 100%</td>
<td>$12.17</td>
<td>35 - 54%</td>
</tr>
<tr>
<td>7</td>
<td>$22.4 - $35.0</td>
<td>$35.64</td>
<td>100%</td>
<td>$19.12</td>
<td>55 - 85%</td>
</tr>
<tr>
<td>8</td>
<td>$22.4 - $35.0</td>
<td>$34.65</td>
<td>99 - 100%</td>
<td>$18.59</td>
<td>53 - 83%</td>
</tr>
<tr>
<td>9</td>
<td>$22.4 - $35.0</td>
<td>$33.65</td>
<td>96 - 100%</td>
<td>$18.05</td>
<td>52 - 81%</td>
</tr>
</tbody>
</table>

Our base-case, scenario 5 (which assumes a $49 ticket price and $0.02 variable operating cost per passenger-mile), generates a positive present value of future operating income under both 7% and 11% discount rate assumptions. In the case of the more realistic 11% discount rate assumption, the total present value of the proposed project equates to roughly $12.7 billion. This means that approximately 36 – 57% of the initial implementation cost of construction could be financed by the future operating income of the project, depending on the exact implementation cost assumption.

Furthermore, this table allows us to visualize which scenarios would be net present value positive after taking into consideration the initial capital construction costs. Each scenario is either colored red to denote that the overall project would be net present value negative, or green to denote that the overall project would be net present value positive. Under the 7% discount rate, scenarios 4, 5, 6, 7, 8, and 9, are net present value positive, assuming initial construction costs are $22.4 billion. This means that a private investor would likely want to invest the initial
capital, in order to get a positive return on their investment. On the other hand, under the 11% discount rate, there is no scenario in which the overall project would ever become net present value positive. Therefore, we can conclude, under this discount rate, that a private investor is unlikely to take on the entire funding for this proposed Hyperloop route. In these net present value negative scenarios, government funding would be required to support the initial implementation costs.
Chapter 8
Conclusion

This report analyzed several aspects of the Hyperloop technology concept, with a focus on assessing the technological and economic feasibility of the proposed system. In comparison to existing modes of transportation, our study concluded that the Hyperloop system would offer numerous advantages—providing the shortest travel time, lowest implementation cost, greatest energy efficiency, least carbon emission, and cheapest ticket price—along the San Francisco to Los Angeles route. In addition, the Hyperloop system would be completely self-sustainable, immune to weather, and resistant to earthquakes. Therefore, we determined that the Hyperloop system would be the most optimal form of passenger transportation in this region of California. This conclusion, however, is entirely contingent upon the successful implementation of this technology—under the assumption that the proposed technology functions properly and achieves the standards outlined in the 2013 white papers. It is important to note that this is a rather hopeful assumption, given the novelty and complexity associated with this type of infrastructure project.

From a technological standpoint, our study concluded that there are many engineering concerns and external risk factors associated with the design of the Hyperloop system. Many scientists argue that creating such a large-scale vacuum system would be theoretically impossible given the current technology that exists today. Other critics claim that any slight temperature gradient would be problematic, as it would cause the Hyperloop tubes to expand or contract. In addition, another major concern is the vulnerability to terrorism. Since the proposed design of
the Hyperloop would be built alongside the California Interstate 5 highway, it would be entirely
exposed, making it virtually impossible to defend against any form of attack. Each of these
design concerns, as well as those outlined in Chapter 2, continue to threaten the viability of the
Hyperloop technology. Nevertheless, as technology advances and new materials are developed,
engineers will likely develop solutions to several of these issues.

Our economic feasibility study established a rough valuation for the proposed San
Francisco to Los Angeles Hyperloop route through a potential revenue and operational cost
analysis. The ultimate goal was to determine whether the project would be net present value
positive, given the significant capital construction costs that would be required as an initial
investment. Our potential revenue analysis concluded that the total annual demand of the system
would exceed the annual capacity of the Hyperloop. Through our ticket pricing model, we also
determined that the one-way ticket price along the route would likely fall within the $31 - $67
dollar range. Chapter 6 outlined our process for estimating the expected operational costs of the
system, as well as the total implementation costs. Finally, we performed a discounted cash flow
analysis to derive a rough valuation from the future flow of operating income throughout the
2020 - 2035 projection period, and beyond, utilizing the perpetuity growth method. Since there
were a ton of assumptions built into this DCF model, we performed a sensitivity analysis to
consider 9 possible scenarios. We concluded that the project would be operationally profitable
in each scenario, under both discount rate assumptions. After taking into consideration the initial
capital construction costs, however, only 6 scenarios were net present value positive, under the
lesser 7% discount rate assumption. Therefore, these 6 scenarios represented the only favorable
conditions in which a private investor would be likely to provide the entire funding for the initial
construction cost investment. Under the rest of the scenarios, the conditions would be
unfavorable for private investment alone and require government funding to support the initial implementation costs.

The purpose of this study was to create a base model for analyzing the Hyperloop technology. Although this thesis focused exclusively on the San Francisco to Los Angeles Hyperloop route, the same methodology could be applied to other potential markets to derive a rough valuation. Between Hyperloop Transportation Technologies and Hyperloop One, there are over 40 Hyperloop routes worldwide, which are currently under consideration. With support growing from around the globe and international funding continuing to pile in, it has become increasingly probable that the Hyperloop concept will eventually be implemented. Still, many logistical issues remain—only time will tell.
Appendix A
Baseline Travel Demand Forecast Data

| Growth Rate | 2.34% |
BIBLIOGRAPHY


ACADEMIC VITA

Jacob T. Covell

Education:

The Pennsylvania State University, College of Engineering, University Park, PA
Schreyer Honors College
Bachelor of Science in Industrial Engineering, with Business and Economics minors

Relevant Experience:

Northeast Wealth Planners, Somerville, NJ
- Supported financial manager with the collection of relevant financial data during meetings with high net worth clients
- Analyzed data, using LEAP financial software to develop an investment strategy designed to meet clients' personal goals
- Researched new investment opportunities, using Morningstar Workstation to identify top performing funds in various asset classes

LDR Capital Management, New York, NY
Asset Management Intern, June 2016
- Analyzed REIT equity security and presented findings of extensive research to the investment team
- Constructed financial models and performed valuations based on projected NAV, FFO, AFFO, and relative comparisons
- Participated in meetings with fund managers, gaining insight into the investment process and portfolio management
- Maintained several actively managed portfolio accounts on Excel, including entering daily trades and reconciling account balances
- Performed a comparative analysis of various asset management firms, using Bloomberg software to compute valuation multiples

Connors Group, Kinston, NC/Tulsa, OK
Consultant, Summer Analyst, May 2015 - Aug. 2015
- Studied the production of numerous aero structure systems and designed manufacturing process flowcharts
- Analyzed flowcharts and process layouts to discover bottlenecks in production and potential cost-savings opportunities
- Proposed process improvement ideas to clients and senior consultants
- Collaborated with a team to develop engineered labor standards at multiple Spirit AeroSystems (subsidiary of Boeing) manufacturing facilities, utilizing EASE: predetermined motion time systems to create a functional software package for the client

Exalos Inc, Langhorne, PA
Sales/Application Engineering Intern, May 2014 - Aug. 2014
- Researched new market opportunities to expand product reach, resulting in an additional $78,000 of sales in one quarter
- Provided technical product support to the Exalos Sales Department and their customers
- Used Salesforce software to distribute mass mailings to clients to introduce new products

Church & Dwight Co., Ewing, NJ
Chemicals Procurement Intern, June 2013 - Aug. 2013
- Created an extensive database and software tool, using SAP to analyze natural disaster risk based on 4,000 supplier locations
- Presented and trained the Operations Management team on the risk assessment tool
- Met weekly with the Vice President of each department to discuss future operations of the company

Industry Involvement:

Personal Robinhood Portfolio
April 2016 - Present
- Cumulative return (as of February 14, 2017): +18.78% versus S&P 500: +12.67%
- Current investments include GPRO, EBIO, and GNW

Penn State Asset Management Group, University Park, PA
Research Analyst, Equities Group, Sept. 2015 - Present
- Conducted market research and performance valuations on several companies in the technology sector
- Prepared research reports and delivered stock pitches to Lead Analysts and Fund Managers

Engineering Economics Stock Market Competition, University Park, PA
Project Manager, Sept. 2014 - Nov. 2014
- Led group of 4 students to place 2nd in a simulated stock market competition with over 40 teams

Technical Skills & Interests:
- Technical Skills: Bloomberg, Morningstar Workstation, Excel, PowerPoint, MATLAB, R, SAP, SQL, Access, SolidWorks, Salesforce
- Interests: travel, guitar, ukulele, soccer, tennis, scuba diving (NAUI certified in 2009), outdoors, and community service
- Studied abroad for one semester at The Anglo-American University in Prague, Czech Republic