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**Title:** Which Transportation Model Better Suits the Needs of California: The High Speed-Rail or the Hyperloop? A Cost-Benefit Analysis

**Abstract**

Transportation is a critical issue facing California. As its population expands, the State will need to develop a new form of travel that will provide its residents with increased mobility and support its growing economy. Two solutions to this problem have risen to the forefront, the High-Speed Rail and the Hypeloop.

This report details a cost-benefit analysis of both of these forms of transportation in order to determine which one would benefit the state the most. We conducted an extensive meta-analysis in order to determine the appropriate cost and benefit variables for these projects. Examples include operations and maintenance costs, time-savings, reliability, safety, sustainability, and passenger productivity. These costs and benefits were discounted at a 7% rate to reflect the U.S. Department of Transportation’s TIGER guidelines for large-scale transportation projects. In the baseline scenario, the net present value for the High-Speed Rail was approximately $10.6 billion and $51.6 billion for the Hyperloop. We also conducted two sensitivity analyses on the discount rate and ridership projections to account for uncertainties in our model.

After a thorough analysis of both of these transportation systems, we recommend that the High-Speed Rail Authority reconsider moving forward with the HSR project in favor of the Hyperloop. Its net present value surpassed the HSR’s in our base case and our sensitivity analyses and would therefore be a more beneficial mode of transportation for society.
Background

By many standards, California’s highways are among the busiest, its airports increasingly crowded, and its infrastructure is straining to serve 38 million residents. The state’s expected population growth, which is estimated to increase to 51 million in 2050, will continue to place demands on its transportation systems and require significant additions to its capacity (Government Accountability Office, 2013). Given the state’s increasing population, the need for faster, more reliable transportation between cities is especially critical to economic growth (Catherine et al., 2011). However, its current modes of transportation are incapable of addressing the needs of the state. For instance, it is difficult for California to expand its highway system or increase the air infrastructure due to the cost-prohibitive nature and limited availability of land for these modifications (Government Accountability Office, 2013).

Since these systems are already at capacity, the California high-speed rail (HSR) project and the Hyperloop have been proposed as potential solutions to the state’s transportation problem. The proposed benefits of these forms of transportation include faster, cleaner, safer and more convenient modes of transportation, compared to driving and flying. However, each of these transportation systems have multiple costs associated with them that could potentially outweigh their benefits.

*High Speed Rail*: The high-speed rail (HSR) system has been envisioned as a way to further increase mobility (Peterman et al., 2009). Starting in the 1980s, proponents of high-speed rail
(HSR) in California began pushing for its development so the state could have an alternative form of transportation. The high-speed rail will include 800 miles of track, run up to speeds of 220 mph and have stops in Los Angeles, San Francisco, Sacramento, the Inland Empire, Orange County, and San Diego (Catherine et al., 2011). The stated benefits of this project include reduced highway and airport congestion, decreased pollution due to fewer automobile and airplane trips, and time-savings for passengers (Romero, 2008). The travel time between Los Angeles and San Francisco is expected to take 2 hours and 40 minutes, which is approximately half the time of car travel (Romero, 2008). The initial completion date for the entire project was slated for 2020, but due to delays, this date has been pushed back to approximately 2033 (California High-Speed Rail Authority, 2012).

**Hyperloop:** As an alternative to the HSR, Elon Musk, the founder of SpaceX, PayPal and Tesla motors, developed a new method of transportation called the Hyperloop. This system of travel is comprised of reduced-pressure, elevated tubes that propel passenger capsules at a maximum speed of 586 mph (Musk, 2013). Its route would mirror California’s Interstate 5 between the Northern San Fernando Valley in Los Angeles to the Hayward/Castro Valley area in San Francisco and will have the ability to travel this distance of 327 miles in approximately 35 minutes. There will be total of 40 capsules that have the capacity to carry 28 passengers each (Musk, 2013). In addition, the Hyperloop will be powered through an array of solar panels that will be fastened to the top of the tube. The design plan proposes construction to begin in 2020 and last approximately 6 years (Musk, 2013).

**Problem Statement:** To fully understand which alternative will be the most beneficial to society and future generations, our research will explore the different costs and benefits that are
associated with the high-speed rail and the Hyperloop. Ultimately, we want to investigate if the Hyperloop is worth building and how it would impact the future transportation of the state.

**Description of Baseline Scenario**

**Key Assumptions:** In order to conduct this analysis, we made several assumptions about these two projects. Due to the relatively new nature of the Hyperloop, transportation experts and researchers have not had sufficient time to conduct a thorough examination of the air travel and car displacement, ridership projections, capital costs and benefit distributions for this transportation system. Therefore, this study uses a meta-analysis to determine high-speed rail projections and ratios for these variables and then mirrors these determine the appropriate Hyperloop figures.

The costs and benefits were discounted at a 7% rate. This is the most appropriate percentage because a significant portion of the HSR project was funded through the U.S Department of Transportation’s ‘Transportation Investment Generating Economic Recovery’ (TIGER) discretionary grant program, which requires participants to discount their costs and benefits by 7% (U.S. Department of Transportation, 2013). We therefore applied the same rate to the Hyperloop so these variables could be comparable. This discount rate also seemed suitable because it accounts for the high risk and uncertainty that are associated with large-scale transportation endeavors. The costs and benefits were discounted over a 50-year period, which includes construction and projected lifespan for each project. We also assumed that all costs and
benefits will occur at the end of the year and benefits will begin accumulating once the construction is complete.

In addition, to ensure the HSR and Hyperloop were as comparable as possible, we only analyzed the portion of the HSR that passes between Los Angeles and San Francisco because this is where the Hyperloop stations will be constructed. This specific piece of rail consists of 520 miles (California High-Speed Rail Authority, 2012), compared to the Hyperloop, which will traverse 327 miles (Musk, 2013).

The last assumption relates to trucks. Since our analysis only includes the passenger versions of the HSR and the Hyperloop; freight vehicles are not relevant in this analysis. If trucks were incorporated into our costs and benefits, we would have to conduct a separate CBA to account for this method of travel.

**Costs**

The costs linked to these modes of transportation include capital costs for the construction period, lifecycle costs, and operation and maintenance costs. All of the costs for the high-speed rail were obtained directly from the California High-Speed Rail 2012 Business Plan. The construction costs for the Hyperloop were taken from its Alpha proposal. However, since this proposal did not include lifecycle or operation and maintenance costs, these values were derived from the ET3 business plan, which is a similar mode of elevated high-speed transport (Oster, Kumada, & Zhang, 2011). The Alpha proposal also did not distribute the costs over the over the projected construction period and lifecycle of the project. Therefore, in order to determine these allocations for the project, we mirrored the HSR’s cost distribution so we could compare these systems.
After determining the associated costs for each project, we increased in order to account for cost overruns that are typical for large-scale transportation projects. We raised the Hyperloop costs by 45% because that is the average rate that projects of these nature typically surpass their forecasted costs (Flyvbjerg, Holm, & Buhl, 2003). However, we did not want to use this rate for the HSR since the current cost projections already reflect a 60% increase from the original amounts (Vranich & Cox, 2013). We therefore determined that 5% would be more reasonable for increasing the costs in order to create a “high cost” projection for this project.

We also increased the expected construction period for the Hyperloop by 33% in order to account for construction delays and uncertainty associated with new types of transportation projects (Flyvbjerg, Holm, & Buhl, 2003). However, we did not do this for the HSR because the most recent business plan for the project already accounts for expected delays (California High-Speed Rail Authority, 2012). The calculated costs for the high-speed rail and the Hyperloop amounted to $94,804,798,705 and $23,286,215,000, respectively.

**Benefits**

The benefits for these forms of transportation were calculated based on travel demand and the effects generated by people switching from driving or air travel to the high speed rail or the Hyperloop. The specific benefits include travel time savings, reliability benefits, reduction in vehicle operating costs, reduction in costs of oil imports, productivity benefits, reduction in parking infrastructure needs, airline operator savings, propagated air delay, safety and sustainability.

The first step in calculating these benefits was determining how many people currently travel between Los Angeles and San Francisco to establish a baseline for the number of potential
riders that would utilize these modes of transportation. Benefits were calculated as they relate to both the HSR and the Hyperloop in relation to air and road travel. Our best estimate for total ridership projections for the HSR was 513,062,962.95 and 375,085,680 for the Hyperloop for a 50 year period, based on an extensive meta-analysis review of similar projects. We expect that 71% of passengers will be diverted from car travel, 27% from air travel, and 2% percent will be new commuters (Brinckerhoff, 2012). We used a 4.47% growth rate, which is the increase in air travel passengers per year between Los Angeles and San Francisco (a form of high-speed travel that is already in existence), for these projections to forecast the ridership rates for the entire lifespan of the project (Brinckerhoff, 2011). Once we were able to predict the amount of people that would ride the HSR and Hyperloop, we used these projections to calculate the aforementioned benefits. The following is an explanation of how each benefit was monetized individually, illustrating the effects of travelers diverting from airplane and automobile and to either the HSR or Hyperloop. The formulas and calculations for all of the benefits are explained in detail in Appendix A and B.

**Time-travel savings:** A decrease in travel time benefits passengers because it allows them to have more time to partake in activities of their choosing. The Hyperloop and HSR both provide automobile travelers with this benefit. Time-travel savings encompasses two populations: 1) those who transfer from road travel to the HSR or Hyperloop and 2) those who choose to remain on the road. The first population’s benefits were found by subtracting the time each projected rider would spend traveling by the HSR and Hyperloop, and subtracting that amount from the time the same trip would have taken to commute by automobile. This time savings was then monetized by using this group’s Value of Time (VOT) of $31.15, which was computed from a table provided by the Department of Transportation (U.S. Department of Transportation, 2011).
The travelers who choose to remain on the road also incur a benefit, as the reduction in automobiles on the highways and freeways will decrease the level of congestion. This value was quantified by multiplying the amount that each car contributes to total highway congestion by the number of anticipated riders for each of the new transportation proposals. This figure was then divided by an Average Vehicle Occupancy (AVO) of 1.925, which was derived from the *California High-Speed Trains Project’s Ridership and Revenue Forecasts* (Brinckerhoff et. al., 2010).

**Reliability Benefits:** Reliability benefits reflect the value travelers gain by using a more dependable source of transportation that is not prone to long delays or congestion, as compared to cars. To account for unpredictable delays caused by traffic, automobile commuters must account for a “buffer time” when embarking on a trip. The Planning Time Index (PTI) derived by the Texas A&M Transportation Institute provides a value that indicates an amount of time that needs to be added to arrive on time to a destination (Schrank, Eisele, & Lomax, 2012). An average PTI80 value of 2.25 indicates for every trip a commuter makes in the Los Angeles and San Francisco areas, 1.25 percent of the time travel expectancy needs to be added to the journey in order for individuals to arrive on time 80% of the time. It is assumed that traveling on the HSR and the Hyperloop will be much more reliable and eliminate the need for a “buffer time” (Schrank, Eisele, & Lomax, 2012).

**Reduction in vehicle operating costs:** Road travelers that switch to the HSR and Hyperloop also receive benefits related to a reduction in car operating and ownership costs. The less vehicle miles one travels, the more he/she will save in vehicle operating costs. These savings include fuel costs, maintenance costs, and vehicle depreciation (U.S. Energy and Administration System, 2013).
**Airline Operator Savings:** Airline operators will also see benefits from these transportation systems. Since the average plane holds 100 passengers, every 100 passengers that are diverted from air travel to HSR or the Hyperloop will reduce the number of airplane trips between Los Angeles and San Francisco by one. This will benefit airline operators because it will reduce air traffic congestion and the costs associated with these delays. Every flight that is removed from the air infrastructure system will result in the avoidance of approximately 11 minutes of potential delay, amounting to approximately $450.00 (Airlines for America, 2013).

**Propagated air delay:** A decrease in delays associated with less airline travelers, will also reduce the propagated delay of airports in the entire system. Reduced propagated delays will mean that other airports will also benefit from the riders diverted to the HSR and Hyperloop. The average delay of propagation multipliers between the Los Angeles and San Francisco areas was 1.53. Therefore, every 100 hours of delay at either of these airports contributes to about 153 hours of delay at other airports (Brinckerhoff, 2012). This number was then multiplied to the previously calculated operator delay costs to calculate the amount of money that would be saved as a result of decreased propagated delays with the implementation of the HSR or Hyperloop.

**Reduction in costs of oil imports:** When car and air travelers switch to the HSR or the Hyperloop, it will result in a reduction in the demand for oil due to the decrease in use of these modes of transportation. Since the U.S. is a large consumer of oil, if it decreases its overall consumption, it would reduce the world oil prices due to the monopsony costs and “price shock” component. (Office of Regulatory Analysis and Evaluation et. al., 2009). The National Highway Traffic and Safety Administration estimates that for each gallon of fuel not used, the monopsony costs will reduce by approximately $0.29. In addition, each gallon of fuel that is not consumed will decrease the total U.S. oil imports by 0.95 gallons (Office of Regulatory Analysis and
Evaluation et. al., 2009). In addition, there is also a price shock component to oil savings, which means that when there is a decrease in oil availability, the prices increase and will reduce the level of U.S. economic output. Therefore, this theory suggests that every gallon of gas that is not purchased in the U.S. reduces the overall oil consumption, saving the country approximately 12 cents per gallon (Office of Regulatory Analysis and Evaluation et. al., 2009). The projected monopsony costs and “price shock” components were used in conjunction with projected fuel efficiency rates of automobiles to calculate the amount of money that would be saved with the reduction of automobile usage.

**Increased productivity:** Passengers that utilize the newly proposed modes of transportation will also have the potential to increase their productivity while traveling. Higher productivity rates allow travelers to conduct tasks such as reading or working while in route to their destination. It is assumed that individuals who transport by car would not be able to participate in other productive activities while traveling, while those who choose to fly would have a slightly higher productivity rate. Those who transfer to the HSR or Hyperloop would be able to be much more productive. To account for this benefit, the following productivity rates were allotted to each type of commuter: Road (0%), Air (33%), HSR (50%), Hyperloop (50%). These percentages were multiplied by the number of hours individuals would utilize each mode of transportation a year, then by the corresponding VOT (value of time).

**Reduction in parking structure needs:** Another benefit associated with the creation of these systems is the reduction in parking structure needs. As more drivers are diverted to these forms of transportation, there will be less demand for parking. Through our meta-analysis, we determined every 365 cars that are taken off the highways a year reduces the demand for one parking space (Brinckerhoff, 2012). Half of this reduction in demand will come from structured
parking and the other half will be from surface spaces. Structured spaces are assumed to cost $1,000 and surfaces spots are estimated to cost $300 each. Based on these assumptions, we were able to calculate the cost-savings of these parking infrastructure reductions.

**Safety:** There are several benefits associated with safety that these systems bring to passengers. For instance, there will be an overall reduction in fatalities and injuries from car accidents due to a decrease in vehicles on the highways (Brinckerhoff, 2012). We then analyzed the accident cost-savings for the HSR and Hyperloop and computed it with the value of a statistical life in order to monetized these benefits.

**Sustainability:** Both the HSR and the Hyperloop would decrease carbon emissions and noise pollution for the surrounding areas. To monetize these benefits, we determined how much carbon each of these systems would emit, the noise pollution they would cause, the aviation emissions savings due to the reduction in flights, and the reduction in car pollution (Interagency Working Group on Social Cost of Carbon, 2010).

**Primary Results**

Our baseline results indicate that the benefits of the Hyperloop will exceed those of the High-Speed Rail. With a 7% discount rate over a 50-year period, its NPV was approximately $51 billion compared to $10 billion for the HSR. The total benefits for the Hyperloop were $325,972,878,545 and its costs were $23,286,215,000.00.

<table>
<thead>
<tr>
<th></th>
<th>HSR</th>
<th>Hyperloop</th>
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<tbody>
<tr>
<td>BCR</td>
<td>1.3</td>
<td>14</td>
</tr>
<tr>
<td>IRR</td>
<td>8.25%</td>
<td>35.55%</td>
</tr>
<tr>
<td>NPV</td>
<td>$10,686,826,374</td>
<td>$51,840,376,808</td>
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**Sensitivity Analyses**
In order to account for uncertainties in our model, we performed two sensitivity analyses to test the discount rate and the ridership projections.

**Discount rate:** Since the discount rate is an integral part of the NPV calculations, we wanted to manipulate this variable to see how sensitive our assumptions are to changes in this value. As previously mentioned, we used a 7% rate for our base case. A partial sensitivity analysis was the most appropriate for this because we wanted to see how the results would change when we lowered the discount rate but held the other variables constant. With a 4.5% discount rate, which is the Moody’s AAA bond rate, the results still maintain that Hyperloop is a more favorable project.

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>HSR NPV</th>
<th>Hyperloop NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>7%</td>
<td>$10,686,826,374.12</td>
<td>$51,840,376,807.51</td>
</tr>
<tr>
<td>4.50%</td>
<td>$64,020,156,666.29</td>
<td>$89,455,758,465.58</td>
</tr>
</tbody>
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**Ridership Projections:** The benefits for each project are directly impacted by the ridership projections. This means that errors in these projections will impact the calculated benefits and could sway the results of the analysis. We therefore reduced the ridership projections by 41% to account for the average amount by which ridership projections are overestimated (Government Accountability Office, 2013). The results of this test indicate an unfavorable outcome for the HSR. The reduced ridership rates caused the NPV to become negative $12.4 billion, indicating that this project’s costs outweigh its benefits. The Hyperloop did not experience the same adverse effects. It’s NPV decreased to $45,313,989,224 from $51,840,376,807 but it still
remained positive. This means that a decrease in ridership will have a detrimental affect on the HSR but not the Hyperloop.

**Limitations**

Despite our best efforts to account for all of the costs and benefits associated with these transportation models, our CBA was impacted by several limitations. Our primary constraint was the limited information on the Hyperloop. Specifically, its business plan accounted for the total construction costs, but did not include operation, maintenance or lifecycle costs. It also projected ridership to be at maximum capacity immediately following the completion of the construction, rather than using a projected growth rate to reach this number after several years. In order to overcome this, we extrapolated the appropriate costs and ridership numbers from similar modes of transportation, such as the ET3 (Oster, Kumada, & Zhang, 2011). However, this also presented a problem because there is also limited information on the costs associated with this transportation system. We therefore used our best estimate for these numbers.

Another limitation that we encountered when conducting our analysis was our inability to account for delays associated air travel such as waiting at security checkpoints or for checked baggage. Since these factors are only associated with air travel because the HSR and Hyperloop will not have security checkpoints or baggage claims, the exclusion of these delays in the time travel savings calculations skews the analysis by making air travel seem like it takes less time than it actually does. If these had been accounted for, the time-travel benefits for both the HSR and Hyperloop would have been higher.

Lastly, it was also difficult to determine the environmental effects that each of these systems poses. For instance, although we conducted a thorough meta-analysis, it was challenging to derive the amount of carbon emissions that each mode of transportation creates. The business
plans did not disclose this information and our research on similar projects presented conflicting information on this issue. We therefore had to use our best estimation to compute these values. It was also difficult to determine the opportunity cost of land for the Hyperloop. If we were able to determine this information, it could have impacted our analysis by increasing the project’s costs. However, since we were unable to determine this value, we did not include it in our CBA.

**Recommendation**

Based on our cost-benefit analysis of the High-Speed Rail and the Hyperloop, our results show that the Hyperloop will be a more beneficial project for the state and its future generations. As the CBA shows, the Hyperloop’s Net Present Value is much greater than that of the HSR’s. However, since the HSR project is already underway and the State has invested significant resources in this project, it may not be possible for California to completely abandon it altogether. In addition, we anticipate that there may be some political pushback from cities that would be granted a station from the HSR and not the Hyperloop, and would therefore not support the suspension of the project. Despite these issues, constructing the Hyperloop would be a wise investment for the state. Whether funded by private money, such as Elon’s Musk’s own company, or public money, the benefits are much more profound than those of the HSR. As evident from our analysis, this investment would not only benefit the financiers, but also the community as a whole.
References


Appendix A
Basic Information

Air Travel
- Number of passengers per flight: \( \frac{39,756,963}{398,858} = 99.68 \approx 100 \) passengers/flight
- Number of domestic flights a year coming out of SF: 169,143
- Number of passengers a year on domestic flights coming out of SF: 16,737,351
- Number of domestic flights a year coming out of LA: 229,715
- Number of passengers a year on domestic flights coming out of LA: 23,019,612
- Number of passengers coming out of SF and LA annually = 16,737,351 + 23,019,612 = 39,756,963

Car Travel
- Current number of road travelers
  - Approximately 6.6 million car trips per year from LA to SF at HSR fares at 77% of airfare
  - Average Vehicle Occupancy (AVO)
    - Business trips: 1.5
    - Commute: 1.2
    - Other: 2.5
    - AVO Equation: \[ .5 * \frac{(1.5 + 1.2)}{2} + 0.5 * (2.5) \] = .675 + 1.25 = 1.925

Cost of traveling from LA → SF or SF → LA
- Road
  - \( \frac{382 \text{ miles}}{21.22 \text{ miles/gallon}} \times \$3.36/\text{gallon} \approx \$60.50/ \text{ one way trip} + \)
    \( (2003\$) \times 0.112(382) = (2013\$) 54.30 = \$114.80/\text{trip/car} \to 114.80/1.925 = \$59.64 \)
- Air
  - Average: $110.5
- HSR: $85.09 (77% of airplane ticket cost)
- Hyperloop: $20
Appendix B
Formulas and Calculations

Travel-Time Savings:
- **Travel Time Savings for Auto Transfers to HSR**
  - Equation: # of riders diverted from road by the HSR *(6-2.66)*(31.15)
  - Equation: # of riders off the road *(travel time of one trip by road - travel time of one trip by HSR) * Value of time for those switching from road to high speed transportation

- **Travel Time Savings for Auto Transfers to Hyperloop**
  - Equation: # of riders diverted from road by the Hyperloop *(6-.58)*(31.15)
  - Equation: # of riders off the road *(travel time of one trip by road - travel time of one trip by Hyperloop) * Value of time for those switching from road to high speed transportation

- **Travel Time savings for Remaining Auto Users:**
  - Equation for travel time saved by road travelers: # of riders diverted from road * (average delay time each auto commuter causes per mile) * (distance commuted per trip in miles) * (VOT for auto)
  - Average of Yearly Delay per auto commuter 2011 (in LA and SF)
    - 61 hours a year
  - Average of Yearly commuters a year (LA and SF)
    - 3,391,550 commuters
  - Average Daily vehicle miles traveled (LA and SF)
    - 94,828,000 miles
  - Average Delay Time per commuter per mile
    - 2.41 minutes
  - Equation for travel time saved by road travelers: # of riders diverted from road * average delay rate per mile * number of miles traveled * VOT road travelers

- **Time Savings/ delay reduction for Air Transfers to HSR**
  - Equation:
    - [(# of riders removed from air traffic because of the HSR * ((34 * $0.73 * 0.019) + (11.45 * $0.73 *(1- 0.019)))) - (# of HSR riders diverted from air * HSR delay projection * $0.73)]
• Time Savings/ delay reduction for Air Transfers to Hyperloop:
  ○ **Equation:** \[ \left( \frac{\text{# of flights removed from air traffic because of the Hyperloop} \times (100)}{100} \right) \times \left( 34 \times 0.73 \times 0.019 + 11.45 \times 0.73 \times (1-0.019) \right) - \left( \text{# of Hyperloop riders diverted from air} \times \text{Hyperloop delay projection} \times 0.73 \right) \]

• Time savings/ delay reduction for travelers that remain in the air:
  ○ **Equation:** \( \left( \frac{\text{# of passengers diverted from air travel/average number of passengers per flight}}{100} \right) \times (0.010478) \times (VOT \text{ for air travelers}) \)

• After researching average delay times of trains around the world similar to the HSR, we determined that a passenger’s average wait time would be approximately 12.5 minutes.

• After looking at the common causes for train delays, we noticed that the majority of them were not applicable to the Hyperloop. Therefore, we assumed that the average delay time for the Hyperloop would be approximately 2 minutes.

• Since we found that the average number of passengers per flight is 100, we assumed that there would be one flight removed from the aviation system for every 100 passengers diverted from air travel to the HSR/Hyperloop. And for every flight that was removed from the system, there would be 11.45 minutes of delay avoided. → from above source (see computation above)

• 398,858 flights/year = 1093 flights/day

• 1093 flights/11.45 mins of delay = Each flight contributes to 0.010478 mins of air traffic delay.
  ○ Therefore, every flight that is removed from air traffic removes 0.010478 mins of delay.

**Reliability Benefits:**

• **Equation for Reliability Benefits for Auto Transfers to HSR:** \( \text{(# of passengers diverted from auto to HSR)} \times (\text{PTI} \times \text{travel time of one trip by road}) \times (\text{Value of time for those switching from road to high speed transportation}) \)

• **Equation for Reliability Benefits for Auto Transfers to Hyperloop:** \( \text{(# of passengers diverted from auto to Hyperloop)} \times (\text{PTI} \times \text{travel time of one trip by road}) \times (\text{Value of time for those switching from road to high speed transportation}) \)

• This Planning Time Index (PTI) 2011
  ○ LA: 2.5
  ○ SF: 2.0
These numbers were computed with the 80th percentile travel time (PTI80), it represents the amount of time that should be planned for a trip to be late for only 1 day a week. A PTI of 2.5, which is the average between LA and SF means that for every 1 hour of travel, 2.5 hours should be planned to make sure that you are on time.


**Reduction in Vehicle Operating Costs:**

**Fuel Savings:**

- **Fuel Savings for Auto Transfers to HSR**
  - **Equation:** 
    \[
    \left(\frac{\text{# of road travelers diverted to HSR}}{AVO}\right) \times \left(\frac{\text{# of gallons of gas for a one-way trip by auto}}{\text{gas price}}\right)
    \]

- **Fuel Savings for Auto Transfers to Hyperloop**
  - **Equation:** 
    \[
    \left(\frac{\text{# of road travelers diverted to Hyperloop}}{AVO}\right) \times \left(\frac{\text{# of gallons of gas for a one-way trip by auto}}{\text{gas price}}\right)
    \]

- Fuel Efficiency and Price projections of Automobiles and Airplanes was taken from the U.S. Energy and Administration System.

- In order to estimate fuel prices and vehicle/airplane efficiencies that extend beyond 2040, the compound annual growth rate (CAGR) was calculated for 2010-2040 and then use it to continue the series through 2063
  - **CAGR:** 
    \[
    \left(\frac{\text{Ending Value}}{\text{Beginning Value}}\right)^{\left(\frac{1}{\text{# of years}}\right)} - 1
    \]
    1. Motor Gasoline (passenger vehicle fuel): 1.38%
    2. Jet Fuel (aviation use): 2.12%
    3. Light-Duty Stock (automobiles): 1.83%
    4. Aircraft: 0.46%

- **Sources:**

**Non-Fuel Savings:**

- **Non-Fuel O&M Savings for Auto Transfers to the HSR:**
  - **Equation:** 
    \[
    \left(\frac{\text{# of road travelers diverted to the HSR}}{1.925}\right) \times (382) \times (0.112)
    \]
Equation: [(# of road travelers diverted to the HSR/AVO * # of miles of a one-way trip by auto * (Cost of Maintenance and Repair + Tires + Depreciation)]

- Non-Fuel O&M Savings for Auto Transfers to the Hyperloop:
  - Equation: (# of road travelers diverted to the Hyperloop/1.925) *(382)* (.112)
- Non fuel costs per automobile were computed by including the costs of M&R, Tires, and the Depreciation of an automobile. The following values were taken from the Minnesota Department of Transportation and then converted to 2013 dollars. They represent the costs that our endured when driving 50% of the time in city driving conditions and 50% of the time in baseline conditions, in cents:
  - Maintenance and Repair: 3.5
  - Tires: 0.9
  - Depreciation: 6.8


### Air Fuel Savings

- **Fuel Savings to Airline Operators due to HSR Transfers Equation:** (# of flights removed from air system by HSR/100 passengers per flight) *(the number of gallons of fuel each flight requires) * (price of airline fuel per gallon)

- **Hyperloop Equation:** (# of flights removed from air system by Hyperloop/100 passengers per flight) *(the number of gallons of fuel each flight requires) * (price of airline fuel per gallon)

### Non-Fuel Savings to Airlines

- Non-Fuel Savings to Airlines from HSR Transfers **Equation:** (# of flights removed because of HSR travelers/100) * (the average flight delay time) * (the cost to airlines for each minute of flight delay)

- **Hyperloop Equation:** (# of flights removed because of HSR travelers/100) * (the average flight delay time) * (the cost to airlines for each minute of flight delay)

- Non- Fuel costs for airliners is about $38.83 per minute of aircraft delay (2012$)
  - Computed by dividing 92 mil system delay minutes and dividing by the 2012 delay costs (minus fuel delay costs)
  - $39.50 (2013$)
**Propagated air delay**

- **Equation:** (Airliner Non-Fuel Operation Costs * 1.53)* (# of riders removed from Air/100)

- We utilized the average delay propagation multipliers (1.53) and multiplied it to the previously calculated operator delay costs. Then we multiplied that product by the number of flights that will be removed with the implementation of the HSR/Hyperloop projects.

**Reduction in the Economic Costs of Oil Imports**

- **HSR Equation:** [(0.95 * (# of passengers diverted to the HSR from road/AVO)) * (# of gallons of gas needed per trip) * $0.43]

- **Hyperloop Equation:** [0.95 * (# of passengers diverted to the Hyperloop from road/AVO) * (# of gallons of gas needed per trip) * $0.43]

- Monopsony Component + Price Shock Component = ($0.266 + $0.116) = $0.382/ gallon of fuel saved = $0.43 (2013$)

**Productivity Increase**

**Productivity Increase for Auto Transfers:**

- **Equation for Productivity Increase for Auto Transfers to HSR:**
  \[(# \text{ of passengers diverted to the HSR from road}) \times (\text{VOT for passengers switching from auto to High Speed transportation}) \times (\text{amount of time one trip takes by HSR}) \times (\text{productivity rate of HSR passenger} - \text{productivity rate of Auto User})\]

- **Equation for Productivity Increase for Auto Transfers to Hyperloop:**
  \[(# \text{ of passengers diverted to the HSR from road}) \times (\text{VOT for passengers switching from auto to High Speed transportation}) \times (\text{amount of time one trip takes by Hyperloop}) \times (\text{productivity rate of HSR passenger} - \text{productivity rate of Auto User})\]

**Productivity Increase for Air Transfers**

- **Equation for Productivity Increase for Air Transfers to HSR:**
(# of passengers diverted to the HSR from air) * (VOT for passengers of High Speed transportation) * (amount of time one trip takes by HSR) * (productivity rate of HSR passenger - productivity rate of Air Passenger)

- **Equation for Productivity Increase for Air Transfers to Hyperloop:**
  (# of passengers diverted to the Hyperloop from air) * (VOT for passengers of High Speed transportation) * (amount of time one trip takes by Hyperloop) * (productivity rate of Hyperloop passenger - productivity rate of Air Passengers)

- The following productivity rates from Parsons Brinckerhoff’s Analysis of the HSR. The productivity of Hyperloop riders was assumed to be comparable to that of HSR riders
  - Road Travel: 0%
  - Air Travel: 33%
  - HSR: 50%
  - Hyperloop: 50%


**Equations:**

- **HSR Equation for passengers from Air:**
  - (# of riders diverted from cars to the HSR *(productivity of passenger on HSR - productivity of person in a plane)

- **HSR Equation for passengers from Road:**
  - (# of riders diverted from planes to the HSR * (productivity of passenger on HSR - productivity of person in a car)

- **Hyperloop Equation from Air:**
  - (# of riders diverted from planes to the Hyperloop * (productivity of passenger on Hyperloop - productivity of person in a plane)

- **Hyperloop Equation for passengers from Road:**
  - (# of riders diverted from cars to the Hyperloop * (productivity of passenger on Hyperloop - productivity of person in a car)

**Reduction in Parking Structure Needs**

- (# of passengers diverted to the HSR or Hyperloop from road travel/AVO) = number of car trips (or cars) taken off the road
- # of cars off the road a year/ 365 = number of parking spaces no longer needed a year
Equations

- **HSR Equation:** \( \text{# of spaces no longer needed a year with HSR} * [0.5 \times $300 + 0.5 \times $1,000] \)

- **Hyperloop Equation:** \( \text{# of spaces no longer needed a year with Hyperloop} * [0.5 \times $300 + 0.5 \times $1,000] \)

**Accident Cost Savings:**

**Fatality Reduction Savings:**

- **Equation for Fatality Reductions of Auto Transfers to HSR:**
  \( \text{(# of riders taken off the road because of HSR)* } \left[ \text{(number of miles per trip by auto) } \times \text{(MAIS rate of fatality per road traveler) } \times \text{(MAIS value of a fatality)} \right] \)

- **Equation for Fatality Reductions of Auto Transfers to Hyperloop:**
  \( \text{(# of riders taken off the road because of HSR)* } \left[ \text{(number of miles per trip by auto) } \times \text{(MAIS Rate of fatality per road traveler) } \times \text{(MAIS value of a fatality)} \right] \)

**Injury Reduction Savings:**

- **Equation for Injury Reductions of Auto Transfers to HSR:**
  \( \text{(# of riders taken off the road because of HSR)* (number of miles per trip by auto) } \times \left[ \text{(the total of MAIS rates for all degrees of injury per road traveler per mile) } \times \text{(the average of MAIS values for all types of injury)} \right] \)

- **Equation for Injury Reductions of Auto Transfers to Hyperloop:**
  \( \text{(# of riders taken off the road because of Hyperloop)* } \left[ \text{(number of miles per trip by auto) } \times \text{(the total of MAIS rates for all degrees of injury per road traveler) } \times \text{(the average of MAIS values for all types of injury)} \right] \)

- Monetized values for fatalities, and accidents categorized on the MAIS scale are reported in the U.S. DOT’s guidance for “Treatment of the Economic value of a Statistical Life.”
  18 Values pertaining to property damage only accidents were reported by the National Highway Traffic and Safety Administration,19 and have subsequently been updated to 2011 dollars by the U.S. DOT.20

- **MAIS:** Maximum Abbreviated Injury Score

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Category Accident Rate (per million VMT) (2010)</th>
<th>Approximated Value (2013$)</th>
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25
<table>
<thead>
<tr>
<th>MAIS Level</th>
<th>Probability</th>
<th>Monetary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIS 6 (fatal)</td>
<td>0.009486</td>
<td>$9,300,000</td>
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<tr>
<td>MAIS 5 (critical)</td>
<td>0.001290</td>
<td>$5,500,000</td>
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<tr>
<td>MAIS 4 (severe)</td>
<td>0.004975</td>
<td>$4,300,000</td>
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<tr>
<td>MAIS 3 (serious)</td>
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<tr>
<td>MAIS 2 (moderate)</td>
<td>0.059418</td>
<td>$435,000</td>
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<tr>
<td>MAIS 1 (minor)</td>
<td>0.634997</td>
<td>$27,800</td>
</tr>
</tbody>
</table>

VMT= Vehicle Miles Traveled


**Sustainability**
- Auto Emissions
- Social Cost of Carbon (SSC) - Discounted at 5%, 3%, 2.5%, in 2007$

**Assume a 2.4 percent increase every year after 2050**

**Equations:**
**Excel sheet available upon request.**