APSC 100 – Hyperloop Track Route Report

Statement of Originality:

We hereby attest that this submission is our own work with the exception of properly cited materials. Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity on the Faculty of Engineering and Applied Science website (http://my.engineering.queensu.ca/policy/Honesty.html) and confirm that this work is in accordance with the Policy.

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Selection of the Route

Preliminary research for selecting a route consisted of identifying locations that would comply with the constraints set by QLoop Consulting. This entailed investigating countries experiencing and expecting substantial economic growth, defined as having gross domestic product growth (GDP) values greater than 4.0%. Within these countries, major centres were identified that could accommodate a large transportation system and were more than 1000 km but less than 1500 km apart. The population densities of the such major centres were then investigated, and the minimum population density was set to 5000 persons per square kilometer. It was found that remaining major centres were in developing countries in Asia and Africa with relatively low GDPs per capita.

The team decided that the Hyperloop should be implemented in a location with high congestion, to alleviate urban stress and decrease the urban heat island effect. The route was also decided to be a major cargo route, connecting major centres with similar major industries to encourage trade and workforce commute. Towards the final stages, the feasibility of routes located between Addis Ababa, Ethiopia and Nairobi, Kenya, New Delhi and Mumbai, India, and Hanoi, Vietnam and Phnom Penh, Cambodia were compared. The most suitable location for a track was decided to be between New Delhi and Mumbai, India. India had a GDP growth of 7.3% in 2018 [1] and New Delhi and Mumbai respectively have population densities of 11,050 and 29,650 persons per square kilometer [2]. In terms of economic growth and population density, this location has the most potential to open a substantial consumer market. Also, the tourism industry in India is flourishing thus constructing a cheaper and more environmentally sustainable alternative to air travel between the two largest cities in India will be significant.

Figure 1: Map of the proposed route between New Delhi and Mumbai, India. The red line represents the aboveground track, whilst the blue and black lines represent the underground tracks. Although not shown in this map, the turns in the track will have minimum radii of 2.5 km to minimise experienced g-forces by passengers.

The route between New Delhi and Mumbai is shown above in Figure 1. The total track length is 1168.9 km, with 1095 km of the track aboveground and 73.9 km of the track underground. Underground tracks will follow a minimal gradient over 30 km to aboveground tracks to minimise g-forces. The purpose of the partial underground tracks is to minimize land usage within the city centres due to population density. Limited land space means relocation of homes will be difficult, and the prevalence of squatter settlements will pose obstacles to organized and legal manners of relocation. The route intersects bodies of water on three occasions, which will be combatted through constructing the track on piles aboveground. Aboveground tracks will cut through rural areas, which consist of farmland with no large roadways.

Stakeholders

QLoop is a stakeholder with direct involvement in the construction of the Hyperloop. They are a significant stakeholder since they are overseeing and relying on the project's success. QLoop intend for the project to offset its capital investment and total expenses within the shortest payback period possible through maximizing profit from different revenue sources such as tickets, investments, cargo transport, and government grants [3]. Furthermore, QLoop would be concerned with the safety measures and precautions taken with respect to construction. They would have to consider the safety of construction workers, residents of the cities and future passengers. QLoop must ensure that implemented safety codes are up to date and at par with the safety precautions outlined by the Indian government, taking into consideration Canadian guidelines as well. QLoop are required to be mindful of the potential environmental impacts and how to minimize any damage. Construction must be ensured to result in the least destruction to agricultural land, minimize resource depletion and air and sound pollution, and it must avoid flooding and chemical runoff.

The other stakeholders influencing the construction of the Hyperloop are the involved construction companies and local residents. It would be in the construction companies' interests to complete this task as they would receive recognition for their contributions towards this revolutionary advancement. The workers for the construction companies would most likely be given special benefits upon completion of the Hyperloop. However, the main concern of construction companies would be the safety of their workers. Considering working conditions in India have different standards from North America and the infrastructure is still developing, the location of the project could be a setback to the companies. Local residents will benefit from this system since it will be readily accessible to them. However, some major concerns for the residents would be the need to relocate in case of route contradiction or conflict. Another issue would be the noise disturbances during construction process.

The stakeholders with the greatest influence in the design of the Hyperloop would be SpaceX and Elon Musk. Elon Musk initially introduced his concept of the Hyperloop, thus his envisions and aspirations are the sources of inspiration for this project. He provided insight and purpose to this project with the criteria for its implementation being in a location where its functionality would thrive the most [4]. In this case, India is a perfect example because the Hyperloop is an alternative transportation system with massively reduced air pollution, that accounts for the needs of increased population density and makes a bold statement for India's identity. As well, SpaceX provided certain parameters for the length of the route. An analysis according to SpaceX claimed that cities less than 1,500 km would be ideal for the Hyperloop implementation [5]. Thus, taking this into consideration, the route was decided to be a 1169 km track between New Delhi and Mumbai. Furthermore, Elon Musk and SpaceX would receive recognition for this revolutionary project. If it were to become successful, the awareness and interest around the Hyperloop would be widespread, other countries would invest towards it and soon it would a common phenomenon worldwide. Elon Musk stated how he made the Hyperloop "open sourced" so others could invest and further develop his idea [6]. Their only concern for this project would be its outcome and whether everything resulted as expected in success.

The stakeholders involved in the success of the Hyperloop after its construction would be the passengers that utilize the transportation system and local businesses. The Hyperloop users would be the greatest stakeholder as the entire success of the project depends upon them. The scale of success will depend upon the passengers' satisfaction, which will be determined through being able to travel safely from New Delhi to Mumbai within one hour. Promised benefits are reduced air and sound pollution, decreased usage and risk of cars, and overall innovative technological stance, which would be applaudable [7]. However, the only potential hinderance to the satisfaction of the users would be the cost of the tickets and the guaranteed safety. The tickets prices will be set at USD$25, thus may pose an issue to some citizens who may not be financially capable to use the Hyperloop considering India's low GDP per capita. Furthermore, there are unforeseeable obstacles that could be encountered since this would be a pilot project. The final stakeholder influenced by the success of Hyperloop would be local businesses. They would experience economic growth due to the influx of customers using the Hyperloop, which would be proportional to their proximity to the station. Like residents, the only underlying concern would be regarding potential relocation due to conflicts of the route.

Social and Environmental Impacts

When planning to construct the Hyperloop in India between its two most densely populated cities, social and environmental impacts were identified. Both positive and negative impacts were analysed, and a financial model was applied to quantitatively analyse their effects.

One positive socioeconomic impact would be the significant decreased travel times for all users of the Hyperloop, resulting in increased leisure time. The public would benefit from increased leisure time through an improvement in quality of life. Furthermore, increased leisure time is proven to benefit labor efficiency, which could consequently increase India's GDP [8]. A second positive socioeconomic impact are the car accidents which the Hyperloop would prevent, since the system would not rely on human operation, eliminating human error. According to a study conducted by Virgin Hyperloop One, a Hyperloop connecting Kansas City and St. Louis over a distance of 400 km would save up to $91 million per year in prevented car accidents [9]. Since the Mumbai to New Delhi Route is 1170 km, USD$266.2 million could be saved annually in preventing car accidents.

A third positive socioeconomic impact is the increased job opportunity and job mobility that would arise due to the connection of India's political and financial capitals. Companies would be able to select from a greater range of prospective candidates when hiring. It could positively impact unemployment rates in either city since a daily commute between them would be feasible. Furthermore, companies would have more competitive candidates for specialised roles and therefore potentially increase company efficiency, stimulating GDP growth. However, a potential negative socioeconomic impact is the increased disparities between urban and rural areas, as well as between economic groups within the cities. The city centres would have the potential for GDP and human development growth due to the Hyperloop, however rural areas would not benefit from this, resulting in increased growth and wealth disparities. This could also potentially attract rural residents, increasing urban sprawl and population density in already significantly dense cities. Furthermore, the Hyperloop would only be beneficial to those who it would be financially accessible to. A crucial issue in Mumbai and New Delhi is the existence of squatter settlements, which could increase in population if inner-city disparities increased.

The Hyperloop promises many positive environmental impacts. A study conducted by researchers at the Helmut Schmidt University concluded that by constructing a 300 km Hyperloop route in Germany, thousands of trucks would be removed from the roads [10]. This would reduce CO_2 emissions by 140,000 tonnes per year, which would be especially useful in India as its rapid economic growth can be attributed to the increase in factories mass producing global products resulting in poor air quality. Another study found that 150,000 tonnes of greenhouse gas emissions could be reduced each year with a Hyperloop route of 150 km [11] due to the Hyperloop's reliance on renewable energy sources. Since the Mumbai-New Delhi route is about 7.79 times longer than this, up to 1,169,000 tonnes of greenhouse gas emissions can be further reduced each year. According to the World Health Organization, 13 of the world's top 20 cities with the worst air pollution are in India, with New Delhi having the worst air pollution in the country [12]. The Hyperloop is predicted to be greener than traditional modes of transportation, like cars and trains [5] and 6 times more energy efficient than air travel, according to the US Department of Transportation [13]. The Mumbai-New Delhi route is the third busiest air route worldwide, with approximately 130 daily flights on this route, thus the implementation of this Hyperloop could drastically improve the air quality around these major centres [14].

On the other hand, the construction of such a large-scale project involves a large carbon footprint since local and imported non-renewable resources, like steel for the tube, will have to be consumed. This may be detrimental to India's environment and result in large quantities of CO_2 emissions from the transportation of materials. Furthermore, since this route will inevitably run through natural habitats and agricultural land, rural farmers and local wildlife will be negatively impacted. The construction of the Hyperloop could also lead to decreased biodiversity and significant habitat loss to native species.

According to a feasibility study completed by Virgin Hyperloop One, a Hyperloop linking Pune to Mumbai, 150 km, could result in USD $55 billion from socioeconomic benefits, like time savings, accident reduction from other forms of travel, and reduced greenhouse gas emissions, over 30 years [9]. Using this figure to estimate the socioeconomic benefit for a Hyperloop between Mumbai and New Delhi, 1169 km, approximately $429 billion can be gained over a 30-year period.

Ethical Considerations

Considering the magnitude of this project and the amount of people it will affect, there are many ethical considerations for the project. There are seven stakeholders involved in this project, and according to PEO's Code of Ethics [15], there are obligations owed by engineers to them.

In general, point number three on PEO's Code of Ethics applies to all seven of the stakeholders. Essentially, point number three suggests that, as a practitioner, a conflict with a stakeholder that may influence the practitioner's actions or judgements, must be avoided or disclosed. This pertains to many possible situations in this project. Since this project is being constructed in a foreign country, it must be considered whether the project should be built to Canadian regulations, or to more lenient Indian regulations. Depending on the stakeholders' views, they would suggest which regulations they believe would have the greatest benefit to them. However, the practitioner must disclose to the stakeholders that they must make that unbiased decision on their own. Since it involves safety, using utilitarianism, they must determine what would be the most beneficial option to society.

Another main point from the PEO's Code of Ethics that is substantially applicable is point four, which suggests that as a practitioner, it must be disclosed immediately to a stakeholder if they believe something may be construed as prejudicial to them as a result of the project. This pertains to several possible situations in this project. One possible way this could be a conflict would be if the public views that project as too environmentally unfriendly. The project will cover a vast amount of land and the construction will destroy many trees, which will be a direct cause of the destruction of some wildlife habitat. Another way this could be a conflict would be if the public does not believe the project demonstrates the ethical principle of utilitarianism. Considering the overall cost of this project, in order for the municipal governments of Mumbai and New Delhi to contribute a necessary sum of money, they will most likely have to implement a new tax on the citizens of the two cities, who may not all be able to afford to pay. Despite India being among the fastest growing economies in the world [16], the GDP per capita is low, indicating substantial wealth disparities. This means that a large percentage of people who potentially pay the imposed Hyperloop tax will not be able benefit from it as many of them will not be able to afford to use it. Both cases could impact the reputations of every stakeholder involved negatively.

Financial Analysis

The financial analysis indicated that it would cost an initial capital investment of $ 35,742,700,000.00 for the construction of the Hyperloop. The numerous factors needed to be accounted for are described in depth in Table 2. Annual operating costs including maintenance costs are outlined in Table 1. Additionally, the total annual revenue generated would amount to $4,753,716,140.38, its sources have been expanded in detail within Table 3. From the calculations in Table 7, it was determined that the time for the project to generate a financial return would be 15 years.

For the Hyperloop project to return a financial return within the estimated 15 years, it must be completed in an efficient and timely manner. The various factors such as the cost of inflation, lost opportunities to investment, cost of borrowing money and the element of risk all must be taken into consideration. The change in value of a USD, can be summarized from the minimum annual return (MARR) [17]. In this case, with a MARR value of 10%, the depreciated net annual cash flow is expressed in the present value of annual cash flow in Table 7.

Table 1: Hyperloop Net Present Value Calculations quoted in current USD (November 2018)

Capital Investment required to build the Hyperloop	$ 35,742,700,000.00
MARR	10%
Annual gross revenue	$4,753,716,140.38
Annual operating expenses	$20,000,000 (Maintenance)
Resource Life	50 years

Table 2: Capital Investment Breakdown quoted in current USD (November 2018)

Cost	**Estimate**	**Explanation**
Construction [4]	$8,353,370,000.00	$11.5 million per mile 1169 km = 726.38 miles 726.38×11.5 = $8.353 billion
Tunneling [18]	$3,621,970,000.00	Cost of tunneling = 48.99 billion rupees/km 48.99 billion rupees × ($1/70.64 rupees) ×73.9 km =$3.622 billion
Permits (land permits, housing relocations) [19]	$23,724,360,000.00	Total cost of building a railway is $27.44 million/km in India = (27.44×1169) – $8.353 billion from construction costs =$23.72 billion
Labor Costs [20]	$4,000,000.00	
Raw Materials:		
Capsule Structure and Doors [20]	$9,800,000.00	

Interior and Seats [20]	$10,200,000.00
Compressor and Plumbing [20]	$11,000,000.00
Suspension and Bearings [20]	$ 8,000,000.00
Total	$ 35,742,700,000.00

Table 3: Annual Gross Revenue Breakdown quoted in current USD (November 2018)

Revenue	Estimate	Explanation
Investments [21]	$210,000,000.00	Predicting that this project will generate the same amount of interest as Hyperloop One.
Tickets [22]	$1,042,440,000.00	Travel hours have been allocated from 5 am to 11 pm while cargo hours are from 11 pm to 2 am and finally, there are 3 hours allocated from 2 am to 5 am for maintenance. Ticket costs: 6720 people/ hour×17 hours/day×365 days/1 year×$25/1 person = $1.042 billion
Cargo [23]	$1,276,140.38	$1,174.49 for 25.2 tonnes transported via road; assuming prices can be set 10x higher for quicker transport, $466.17/tonne. 3 hours are set aside to transport cargo, 500 kg of cargo could be transported in one pod and have one pod dispatched every 6 minutes. Thus, 5 pods arrive every hour, 15 pods a day 7.5 tonnes a day = 7.5×466.17×365=$1.276 million
Government grants [3]	$3,500,000,000.00	India has $74.2 billion allocated to improve the country's railways, airports and roads. Thus, it can be assumed that approximately $3.5 billion would be invested towards the Hyperloop given all the socioeconomic and environmental benefits.
Total	$4,753,716,140.38	

Conclusion

The implementation of the Hyperloop between New Delhi and Mumbai will result in more benefits than disadvantages. Given the route fits all the requirements and constraints prescribed by QLoop as well as those given by SpaceX and identified by the team, it is a suitable choice. With 130 daily flights between Mumbai and New Delhi and 23 million train users in the country everyday [14], the densely populated centres ensure that there will be a high demand for the transportation system. Furthermore, this energy efficient transportation alternative could significantly decrease India's carbon footprint and improve their quality of air. The project is predicted to generate a financial return within 15 years, with resource life at 50 years, therefore generating USD$11.2 billion before materials need to be replaced. On top of this however, modelling has shown that social and environmental benefits could save India up to USD$430 billion. Although there are disadvantages like the potential increase in disparities between rural and urban areas, as well as destruction to the environment, these disadvantages are minute in comparison to the potential benefits. The Hyperloop offers improvement to the quality of life of citizens, air quality, increased employment opportunity, and substantial economic growth with minor disadvantages that are not unsolvable. Therefore, the Hyperloop should be implemented between New Delhi and Mumbai.

However, it must be considered that this is viewed from a foreign perspective bias, which may impact the analysis to be less sensitive to stakeholders like citizens. Although only great benefits and minute disadvantages were identified, impacts may be felt stronger by different groups of people due to culture, race, or circumstance. Considering the low GDP per capita of the country, if the project were taken public by the government, taxes may be raised by a margin that is significant to most citizens. Furthermore, the clearing of agricultural land for the system may have a more significant impact than anticipated since agriculture is the main source of income for a significant number of rural citizens.

Ethical Scenarios

Sexism in the Workplace

In this situation, there is a conflict between a male and female civil engineer, regarding a lack of trust due to the gender of an individual. This issue was expressed on numerous occasions, during team meetings, and concerns shown in personal emails. There are multiple approaches to address this situation, but it is necessary to evaluate the different options and choose the method that would be most beneficial for both parties.

A possible approach to the situation would be to directly terminate Michael from the project for his discriminatory actions and hate crime. He would be let go from the Hyperloop project for going against fairness and loyalty in PEO's Code of Ethics [15]. This type of approach embodies the ethical principle of utilitarianism. It would allow for the benefit and happiness for the greatest number of people because the root of the problem would have been removed thus, Renata and other female engineers in the workspace would not have to be concerned with his behaviour. However, although this approach would solve the issue immediately, it would be a short-term solution. In the future, to wherever Michael continues to work, he would still embody misogynistic characteristics and the cycle would restart.

An alternative approach would be to conduct a one-on-one meeting between the team leader and each conflicting individual. It would be wise to discuss and elaborate on the issues Renata has been experiencing. The team leader should acknowledge her concerns and notify her that the situation is being dealt with. Afterwards, during the discussion with Michael, the reasons for his dispute against female engineers and why he does not instill trust in them should be discussed and elaborated. After hearing what Michael has to say, and concluding that Renata's claims were true, the team leader should enroll him a workshop on respect and dignity to educate him. This would utilize the ethical principle of rights ethics.

Another possible approach would be to take both engineers and hold a discussion with the team leader together. Implementing the ethical principles of virtue ethics, have both individuals share their points of the story and come up with a common solution, a compromise. This type of approach, although clearing the immediate issue, would not solve the problem of sexism in the workplace in the long run as only middle ground was met.

The recommended approach from the possible approaches above, would be to utilize rights ethics. This would be the most suitable because all human beings are subject to universal human rights regardless of their sex, gender, race, or religion [15]. Thus, no matter how severe the discrimination, the matters need to be resolved with Michael realizing his mistakes. If the workshop results in success, it would be beneficial for both parties as Michael will understand his problems and would be able keep his job while Renata and other potential female engineers affected by this hate crime can continue working in peace.

Conflict due to Ethnic Differences

In this situation, a conflict arose between a manager, Rachel, and an engineer, Jason, due to ethnic differences under stressful conditions due to deadlines not being met. Jason is of Indigenous heritage and has an annual moose hunt with his family for one workweek and Rachel has been dropping racist remarks to him and implying that he is unfit for the job. There are multiple ways to approach this situation following various ethical principles, each having sizeable effects on the team and individuals. The main question at hand here is whether respect for Jason's culture or the project is more significant.

One of the key issues is Rachel's discriminatory behaviour. If Rachel believes Jason is not meeting work expectations, she should provide evidence and speak to him to address the issues. This would be following duty ethics as she would be forced to follow workplace rules regarding dissatisfaction with another employee's work. However, if Rachel were given the power to approach Jason about his work ethic with no consequences for her discriminatory behaviour, she would break duty ethics as the PEO's Code of Ethics states all practitioners should be treated fairly regardless of race [24]. Furthermore, tension may build up within the team as colleagues may take a stand and refuse to work if equality is absent in the workplace. Following duty ethics is impossible in this case since Rachel would not be able to follow one set of rules without breaking another.

An alternative solution would be to monitor Rachel's behaviour around Jason and speak to her casually to evaluate whether she is discriminating against Jason because of his ethnicity. If confirmed, she should be spoken to about the foundations of her racism and offered help to implement an unbiased perspective. If that is unsuccessful, this situation should be reported to a superior who can professionally address this issue since this breaks the Professional Engineer's Code of Ethics [24]. This follows virtue ethics since a virtuous person would not confirm their suspicions of racial discrimination and instead take the time to confirm such suspicions before reporting them. This would benefit Rachel as she would be given a chance to reflect on her actions and change her behaviour. However, this may negatively impact Jason as he may feel unappreciated and discriminated against if Rachel suffers no consequences.

Another alternative that would fully consider the team would be to consider utilitarianism. Although the conflict is mostly constrained to Jason and Rachel, the team is affected due to the lack of progression of work and tense team behaviour. If the wellness and success of the team were the only factors considered, speaking to Rachel about her behavior and asking Jason to stay for the week would be the solution to the problem. Rachel would be professionally confronted about her discriminatory behaviour, resulting in a plan to ensure she treats everyone fairly. This would be an optimal solution for her as she would not suffer any consequences and she would be given a chance to remediate her relationship with Jason. On the other hand, Jason may feel as if his culture is not being respected and that he is being asked to disregard his family's tradition, resulting in him wondering if it is because he is Indigenous.

Approaching this situation, it would be best to consider utilitarianism and virtue ethics. Since the project's progress was unpredictably haltered, it would be advisable to clearly iterate to Jason that a request for him to reduce his time off would be helpful to the team and project's success. Before this action is taken, it would be advisable to speak to Rachel about her behaviour in an unprofessional setting. Further steps should be taken if her behaviour is found to be intentional, and Jason should see action taken against her so that he can work comfortably in a safe environment. This solution will provide Jason comfort knowing that his colleagues recognize his efforts and treat him with equal respect. Furthermore, respecting his request to take time off for his culture is made imperative. Additionally, Rachel will suffer consequences for her discriminatory behaviour and change, otherwise, she should be taken off the project. Since this respects Jason's request to respect his culture, benefits the team, and aims to resolve issues due to discrimination, it is the best approach to take.

Conflict due to Cultural Differences

In this scenario, a conflict arose when representatives of India stated that they expect generous gifts as part of doing business with them. Gift giving in exchange for business goes against the company's policy, as well as the code of ethics in the PEO. Ethical solutions were devised to overcome the cultural differences with respect to business transactions.

Taking aside cultural differences, clearly gift giving should not be undertaken, as it could be viewed as an unethical method of bribe. Legal prosecution and lawsuits may be a consequence of this, and the company may be held accountable for it in situation of fault.

The broad ethical principle that is most useful to address this issue is duty ethics. Duty ethics is concerned with whether an action is right or wrong based on a series of rules, rather than based on the consequences of the action. Thus, it is wrong as an engineer to pay or accept a gift or commission to secure work, even though the company may lose partnership with the client, possibly leading to the termination of the engineer.

A possible approach to dealing with the conflict is to just ignore it, by not partaking in gift giving with the client and by also not talking to the client about the provincial and company's policy on gift-giving. One could hope that by avoiding this difficult conversation with the client, the client would not notice or mind that they do not get to receive any gifts, and the conflict would blow over. However, this approach is not recommended, since it does nothing to attempt to solve the problem on a basis of understanding. Furthermore, as an engineer, there is an obligation to disclose such matters to the company, since it could jeopardize the company's relationship with the host country.

Thus, the first step an engineer in this position should take to address this issue is talking to a superior about the details of the situation, concerns with the legal implications of partaking in gift giving but also possible negative impacts on the company's relationship with the client if with incompliance with their wishes.

A superior should then speak to the clients about how although their culture is recognized and respected, gifts are against company and provincial policy, and so the company is legally unable to give them gifts in part of doing business with them. A superior should do this because this is a sensitive topic, and their position would validate the company's stance on gift giving to the client.

This could be upsetting news to the client, so it would be wise that a superior brings up this topic in a sensitive manner, and that they show a genuine understanding of the client's position and their culture. It should be mentioned that to give gifts is out of the company's hands, however, the company would still be very eager to work with the client and hopes that business can continue forward.

Conflict due to Regulation Differences

In this scenario, there is a conflict between one of the main funding agencies of the host country and the practitioner. Since safety regulations from the host country are more relaxed than the safety regulations required under law in Ontario, the host country indicates that, until unnecessary costs are cut, they will not sign the contract. The practitioner, however, believes that cutting safety features goes against PEO's Code of Ethics.

A possible approach to resolve this conflict would be to accept the host country's demands and cut all unnecessary safety related costs, based off their regulations. This would be considered respectful to the host country and would build a stronger relationship with them for future business affairs, as well as reduce the conflict for the current project, ensuring a successful outcome. The only drawback would be that it could be construed as unethical according to PEO's Code of Ethics.

An alternative approach to resolve this conflict would be to indicate to the host country that the project may not carry out unless they agree that no safety measures will be cut. If the terms are accepted, then the project will continue with no ethical uncertainties. Unfortunately, forcing the host country to agree to these terms could jeopardize the relationship with them and potentially cause the project, as well as future business affairs, with the country to be terminated.

Another alternative approach to resolving this issue would be to only agree to their suggested cuts conditionally. Essentially, the cuts suggested by the host country would be analyzed and deemed appropriate or not for the given situation. If an agreement cannot be reached between the two parties, the project should be terminated. The drawback with this approach is that the stance taken by the company could be inconsistent. Moreover, opinions could be swayed easily, and this system could become corrupted.

The recommended approach for this specific situation is the first one suggested. This would be suitable as it is respectful to the host country and would benefit the overall project by avoiding conflict. Since this could be deemed contrary to PEO's code of ethics, in order to remain ethically correct, utilitarianism could be argued. Since the relationship between the two countries would be strengthened and money would be saved, the overall project would be improved, meaning society would benefit.

Vehicle Optimization

Propulsion System

The propulsion system used for the prototype vehicle was a belt system comprised of a rubber band that connected the motor shaft to the rear axle, which turned the rear wheels and propelled the vehicle. The motor shaft spun too quickly for the axles to spin, and changes had to be made to the design of the system since the rubber band would not stay in place. By the end of testing, the wheel was attached directly to the motor shaft to generate enough power to get the vehicle to move. Although the final performance was well received, the propulsion system in place was improvised and thus must be iterated for reliability and improvement.

The most significant design parameter in this case was the mechanism of the belt system. The failure of the proposed propulsion system was mainly due to the belt slipping off the motor shaft and the ratio of the sizes of the shaft and the axle. Since the motor shaft had a speed of 8000 rpm with a small surface area, the band would continuously slip off during trials. Furthermore, since the diameter of the shaft was substantially smaller than the diameter of the axle, there was not enough torque being provided to spin the axles. These two problems can be solved through implementing gears onto the shaft and axles.

The radius of the motor shaft was 0.00115 m [25] and the radius of the axle was 0.0050(5) m. By implementing gears onto the shaft and axles, the need for a belt system will subside and the gear ratio will determine the velocity of the vehicle, independently of the radii of the motor shaft and axle.

$$Gear\ ratio = \frac{driving\ gear}{driven\ gear} \tag{1}$$

$$\omega_a = gear\ ratio \times \omega_m \tag{2}$$

where ω_a is the angular velocity of the axle and ω_m is the angular velocity of the motor, at 838 rad/s.

$$v_t = \omega_a \times r_w \tag{3}$$

where v_t is the tangential velocity of the vehicle and r_w is the radius of the wheels, at 0.0190(5) m.

Table 4: Effect of decreasing gear ratio on the tangential velocity of vehicle.

Gear Ratio	Angular velocity of motor [rad/s]	Angular velocity of axle [rad/s]	Radius of wheels [m]	Tangential velocity of the vehicle [m/s]
2.00	838	1680	0.0190	31.8
1.00	838	838	0.0190	15.9
0.667	838	559	0.0190	10.6
0.500	838	419	0.0190	7.96
0.400	838	335	0.0190	6.37
0.333	838	279	0.0190	5.31
0.286	838	239	0.0190	4.55
0.250	838	209	0.0190	3.98
0.222	838	186	0.0190	3.54
0.200	838	168	0.0190	3.18

As seen in Table 4, decreasing the gear ratio will decrease the tangential velocity of the vehicle. However, selecting the greatest gear ratio may result in a problematic situation since the extremely high angular velocity of the axle, which is equal to the angular velocity of the wheels, will result in the wheels losing traction with the ground. This was an observed problem from our past trials due to the lack of torque available to overcome static friction. Even implementing a gear ratio of 0.200 would have a significant impact on the performance of the vehicle, since the highest velocity obtained from past trials was 1.115(5) m/s. Therefore, replacing the belt with gears in the propulsion system will result in substantially higher velocities.

Levitation System

The levitation system used for the model was a wheel-based system. This was a simple system that relied on the implemented two axles and three wheels to levitate. Chopsticks were attached to the chassis of the model and used as axles. Wheels were attached to the end of the chopsticks in order to levitate the model and allow it to propel itself forwards. Based off the material of the wheels, the material of the track as well as the weight of the model, the forces of friction were calculated.

Static friction equation:

$$Fr_s = \mu_s N = \mu_s(mg) \tag{4}$$

$$Fr_s = (0.0500)(0.900kg)(9.80m/s^2)$$

$$Fr_s = 0.441\ N$$

Kinetic friction equation:

$$Fr_k = \mu_k N = \mu_k(mg) \tag{5}$$

$$Fr_k = (0.0350)(0.900kg)(9.80m/s^2)$$

$$Fr_k = 0.3087\ N$$

This model recorded a high 7/8 on testing day, however many iterations could be implemented. A significant iteration to the system would be the addition of magnets to the bottom of the chassis, as well as rubber bands to the wheel. Considering the relationship between the mass of the vehicle and its acceleration, increasing the coefficient of friction through using rubber bands will allow the vehicle to weigh less than its initial weight and provide the same force of friction. Since the previous values of friction worked well, using the new coefficients of friction for rubber on aluminum [26], the ideal weight of the car may be calculated.

$m = \frac{Fr_s}{\mu_s g} = \frac{0.441}{(0.640)(9.80m/s^2)} m = \frac{0.441N}{(0.640)(9.80m/s^2)} = 0.0703\ kg$

With the ideal mass of the vehicle now being determined as 70.3 grams, using the dimensions as well as given strength of the magnet (*8754J/m³*), the number of magnets required can be calculated.

$F_{Magnet} = -m_{ideal\ model} g + m_{model} g$

$F_{Magnet} = -(0.0703kg)(9.80m/s^2) + (0.9kg)(9.80m/s^2) = 8.13106\ J/m$

$m^3_{required} = F_{Magnet}/F_{Magnet\ Strength}$

$m^3_{required} = (8.13106J/m)/8754J = 0.000929m^3$

Chassis System

For the implemented model, the chassis system primarily consisted of a thin cardboard base with another cardboard platform for the second tier. The overall shell of the vehicle was constructed from recycled plastic to imitate the ideal aerodynamic shape of the Hyperloop. Since cardboard alone is weak, the base began to bend at areas under stress. To accommodate this concern, chopsticks were utilized as reinforcements to strengthen and straighten the base. At testing, the vehicle chassis received a grade of 7/8 and the performance only acquired an 81.25%. Clearly then, there were areas where the chassis could be improved.

One area of iteration would be to use a stronger chassis. A sturdier alternative to the cardboard plank would be to use painter sticks glued together to make a 3D frame. These painter sticks would be free of cost, much lighter, stronger and easier to work with. Since the first model also had its centre of mass far from the rear wheel drive, another area of iteration would be to strategically place the components of the vehicle for the ideal centre of mass.

$$x_{cm} = \frac{1}{M_{total}} \sum m_i x_i \qquad (6)$$

Table 5: Chassis components contributing to the centre of mass of the vehicle

Variable	Component	Mass (kg)	Distance from origin (inches)
X_{cm}	The centre of mass placed in the center of the rear wheel	-	0.75
m_1	OSEPP Small R360 Brushed DC Motor	0.049 kg [27]	3.375
m_2	Breadboard	0.013 kg [28]	5.25
m_3	Arduino UNO board	0.025 kg [29]	7.125
m_4	9V Battery Pack	0.038 kg	?

Using **Error! Reference source not found.** as a reference, the location of the components can be mapped linearly along the x-axis as shown in **Error! Reference source not found.** in Appendix B. The locations of the components outlined in Table 5 are determined based on their functionality for the vehicle.

$$x_{cm} = \frac{1}{M_{total}} \sum m_i x_i = \frac{x_1 m_1 + x_2 m_2 + x_3 m_3 + x_4 m_4}{(m_1 + m_2 + m_3 + m_4)}$$

$$0.75 = \frac{(3.375)(0.049) + (5.25)(0.013) + (7.125)(0.025) + (0.038)x_4}{(0.049 + 0.013 + 0.025 + 0.038)}$$

$$x_4 = \frac{-0.318}{0.038} = -8.368\ inches$$

Therefore, to obtain an ideal center of mass on the rear wheels of the vehicle, the battery pack must be placed 8.638 inches to the left of the origin. This could be iterated by having an additional stick extending from behind the vehicle in order to accommodate m_4. By implementing the ideal centre of mass on the rear wheel, it exerts a maximum normal force on the wheel. This subsequently increases the traction force between the wheels and the surface as $F_{traction}$ is directly proportional to F_N. Once this is optimized, it will allow the vehicle to accelerate quicker and thus reach a maximum speed sooner.

Integration System

Since there was not a physical integration system on the vehicle, the integration specialist was responsible for calculating the acceleration of the model. From phase 2, the acceleration of the vehicle was calculated by the equation below, where F_M is the applied force from the torque provided from the motor, F_A was the drag force and F_R was the force of rolling friction.

$$a = \frac{F_M + F_A + F_R}{m} \tag{7}$$

Given that the force which drives the car is the torque (F_T), the drag (F_A) is the negative coefficient of air resistance times the velocity (-cv), and the rolling friction is the coefficient of rolling friction times the weight ($-\mu_r mg$), we can rearrange Equation 5 as:

$$a = \frac{[(F_T) + (-c\ \ ) + (-\mu_r mg)]}{m} \tag{8}$$

From phase 2, the acceleration of the vehicle was calculated to be 3.01m/s^2. During track testing, our vehicle scored 7/8 on its performance. Upon reflection and feedback, the acceleration could have been improved by removing unnecessary mass off the vehicle.

Since the chassis would be improved by using a wooden slab of similar mass instead of the cardboard chassis, the stronger base would make the 4 wooden chopsticks used as reinforcements unnecessary. Each chopstick massed 1.4g [30], thus removing 4 chopsticks would remove about 5.7g off the vehicle.

Furthermore, the four passenger models (each 3cm^3 large) were molded from a heavy putty, totalling to 30g. Styrofoam has a mass of approximately 0.05g/cm^3 [31] thus, using Styrofoam to make these passengers would reduce the total mass of the vehicle by 29.4 g.

$$mass\ of\ passengers\ using\ Styrofoam = 4 \times 3cm^3 \times \frac{0.05g}{cm^3} = 0.6\ g \tag{9}$$

The mass of the vehicle in phase 2 was 900g. After iteration, the mass of the improved vehicle with the chopsticks and putty passengers removed would be 864.9g.

Table 6: Summary of variables, their values, units, and reasoning for Equation 5

Variable	Value	Unit	Reason for value
Torque (F_T)	3.35	N	Calculated by propulsion specialist

Coefficient of air resistance (c)	0.30	N/A	Average coefficient of air resistance of a modern car ranges from 0.25-0.35 [4].
Velocity (v)	1.12	m/s	Measured speed at testing.
Coefficient of rolling friction (μ_r)	0.0010	N/A	Value for a train wheel on a steel track is approximately 0.001 [3].
Mass of the vehicle (m)	0.8649	Kilograms, kg	Mass of vehicle before iteration, minus the mass removed from chopsticks and putty passengers.

Substituting the values found in Table 6 into Equation 5, the acceleration after iteration is calculated to be 3.47m/s^2.

$$a = \frac{\left[3.35N\ + (-0.3 * 1.12m/s) + (0.001 * 0.8649kg * -\frac{9.81m}{s^2})\right]}{0.8649kg} = 3.47\ m/s^2$$

Team Health

Following our meeting with Aphra Rogers and Paul Hungler about our team health in phase 2, we were motivated to work harder for a better grade. We had a lot of trouble meeting deadlines for submission 5, so we decided to create internal deadlines for each deliverable on the report. We also made sure to leave ample time before the due date to edit and revise the document and to account for any unexpected disturbances. Learning from our past mistakes, we placed priority on the team report and agreed to finish the team portion two weeks before the deadline. There was some confusion over the requirements of some portions resulting in extensions being placed, which were met the next week.

Communication as a group improved, which was noticed by the increased volume of discussion and questions asked. There was much more collaboration since individuals worked to finish portions earlier, which allowed other team members to edit and revise, improving our quality of work. There was only one setback due to miscommunication occurred about the work distribution of the ethical scenarios, but we had ample time to correct this. Furthermore, people were more on time to meetings, replied to messages more quickly, and were noticeably motivated to put in more effort into this report.

The impact of our improvements was varied and affected not only the completion of this report but other schoolwork as well. Better time management and stricter deadlines resulted in a less stressful process to write the report, since the completion of the report was gradual, rather than last-minute. This also resulted in more time for us to revise and edit our drafts, which resulted in increased satisfaction. We also found that we had more time to focus on schoolwork, without having to worry about this report. This all resulted in an improvement in the quality of our work and increased levels of confidence in our submission.

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Appendix A: Calculations for the financial analysis

Table 7: Hyperloop Economics Breakdown quoted in current USD (November 2018)

Year	Capital Investment	Gross Revenues	Expenses	Net Annual Cash Flow	Present Value of Annual Cash Flow	Net Present Value
0	-30,561,600,000	0	0	-	-35,742,700,000	-35,742,700,000.00
1		4.75E+09	-2.00E+07	4,733,716,140	4,303,378,309.44	-31,439,321,690.56
2		4.75E+09	-2.00E+07	4,733,716,140	3,912,162,099.49	-27,527,159,591.08
3		4.75E+09	-2.00E+07	4,733,716,140	3,556,510,999.53	-23,970,648,591.54
4		4.75E+09	-2.00E+07	4,733,716,140	3,233,191,817.76	-20,737,456,773.78
5		4.75E+09	-2.00E+07	4,733,716,140	2,939,265,288.87	-17,798,191,484.91
6		4.75E+09	-2.00E+07	4,733,716,140	2,672,059,353.52	-15,126,132,131.39
7		4.75E+09	-2.00E+07	4,733,716,140	2,429,144,866.84	-12,696,987,264.56
8		4.75E+09	-2.00E+07	4,733,716,140	2,208,313,515.31	-10,488,673,749.25
9		4.75E+09	-2.00E+07	4,733,716,140	2,007,557,741.19	-8,481,116,008.07
10		4.75E+09	-2.00E+07	4,733,716,140	1,825,052,491.99	-6,656,063,516.08
11		4.75E+09	-2.00E+07	4,733,716,140	1,659,138,629.08	-4,996,924,887.00
12		4.75E+09	-2.00E+07	4,733,716,140	1,508,307,844.62	-3,488,617,042.38
13		4.75E+09	-2.00E+07	4,733,716,140	1,371,188,949.65	-2,117,428,092.73
14		4.75E+09	-2.00E+07	4,733,716,140	1,246,535,408.78	-870,892,683.95
15		4.75E+09	-2.00E+07	4,733,716,140	1,133,214,007.98	262,321,324.03
16		4.75E+09	-2.00E+07	4,733,716,140	1,030,194,552.71	1,292,515,876.73
17		4.75E+09	-2.00E+07	4,733,716,140	936,540,502.46	2,229,056,379.19
18		4.75E+09	-2.00E+07	4,733,716,140	851,400,456.78	3,080,456,835.98
19		4.75E+09	-2.00E+07	4,733,716,140	774,000,415.26	3,854,457,251.23
20		4.75E+09	-2.00E+07	4,733,716,140	703,636,741.14	4,558,093,992.37
21		4.75E+09	-2.00E+07	4,733,716,140	639,669,764.68	5,197,763,757.05
22		4.75E+09	-2.00E+07	4,733,716,140	581,517,967.89	5,779,281,724.94
23		4.75E+09	-2.00E+07	4,733,716,140	528,652,698.08	6,307,934,423.01
24		4.75E+09	-2.00E+07	4,733,716,140	480,593,361.89	6,788,527,784.90
25		4.75E+09	-2.00E+07	4,733,716,140	436,903,056.26	7,225,430,841.17
26		4.75E+09	-2.00E+07	4,733,716,140	397,184,596.60	7,622,615,437.77
27		4.75E+09	-2.00E+07	4,733,716,140	361,076,906.00	7,983,692,343.77
28		4.75E+09	-2.00E+07	4,733,716,140	328,251,732.73	8,311,944,076.50
29		4.75E+09	-2.00E+07	4,733,716,140	298,410,666.12	8,610,354,742.62
30		4.75E+09	-2.00E+07	4,733,716,140	271,282,423.74	8,881,637,166.36
31		4.75E+09	-2.00E+07	4,733,716,140	246,620,385.22	9,128,257,551.59
32		4.75E+09	-2.00E+07	4,733,716,140	224,200,350.20	9,352,457,901.79
33		4.75E+09	-2.00E+07	4,733,716,140	203,818,500.18	9,556,276,401.97
34		4.75E+09	-2.00E+07	4,733,716,140	185,289,545.62	9,741,565,947.59
35		4.75E+09	-2.00E+07	4,733,716,140	168,445,041.47	9,910,010,989.06
36		4.75E+09	-2.00E+07	4,733,716,140	153,131,855.89	10,063,142,844.95
37		4.75E+09	-2.00E+07	4,733,716,140	139,210,778.08	10,202,353,623.03
38		4.75E+09	-2.00E+07	4,733,716,140	126,555,252.80	10,328,908,875.82
39		4.75E+09	-2.00E+07	4,733,716,140	115,050,229.82	10,443,959,105.64
40		4.75E+09	-2.00E+07	4,733,716,140	104,591,118.01	10,548,550,223.65
41		4.75E+09	-2.00E+07	4,733,716,140	95,082,834.56	10,643,633,058.21
42		4.75E+09	-2.00E+07	4,733,716,140	86,438,940.51	10,730,071,998.72

43		4.75E+09	-2.00E+07	4,733,716,140	78,580,855.01	10,808,652,853.73
44		4.75E+09	-2.00E+07	4,733,716,140	71,437,140.92	10,880,089,994.64
45		4.75E+09	-2.00E+07	4,733,716,140	64,942,855.38	10,945,032,850.02
46		4.75E+09	-2.00E+07	4,733,716,140	59,038,959.43	11,004,071,809.46
47		4.75E+09	-2.00E+07	4,733,716,140	53,671,781.30	11,057,743,590.76
48		4.75E+09	-2.00E+07	4,733,716,140	48,792,528.46	11,106,536,119.22
49		4.75E+09	-2.00E+07	4,733,716,140	44,356,844.05	11,150,892,963.27
50		4.75E+09	-2.00E+07	4,733,716,140	40,324,403.68	11,191,217,366.96

Appendix B: Figures for the Iterated Chassis System

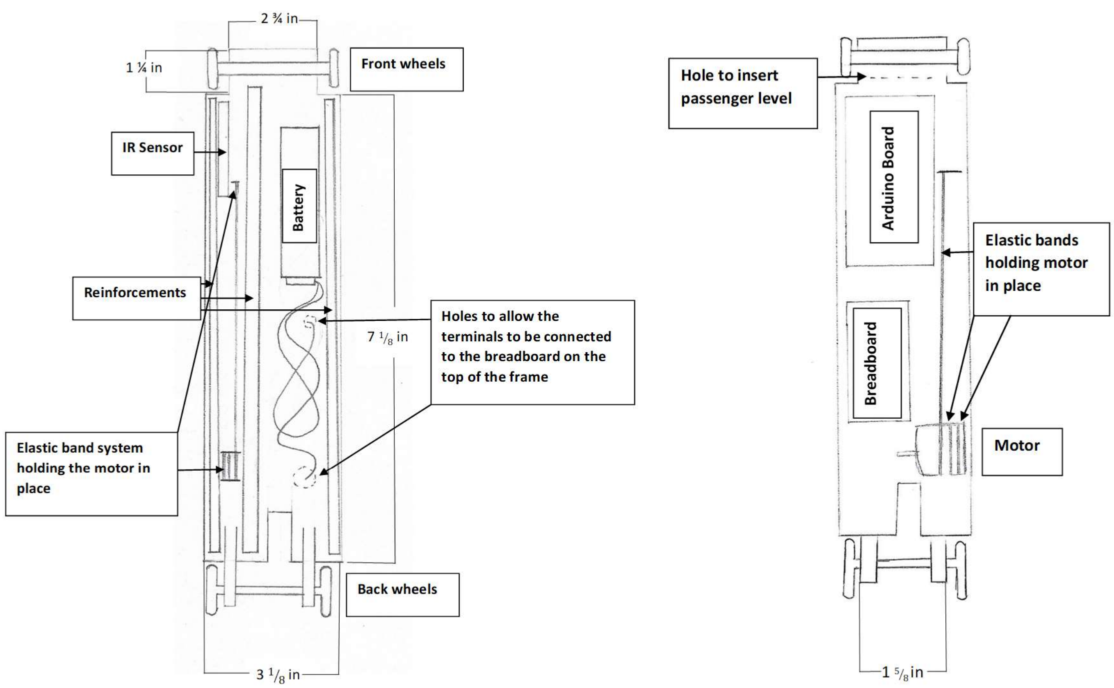

Figure 2: Bottom and top views, left and righthand diagrams respectively, of the final vehicle with dimensions in inches and details of important components.

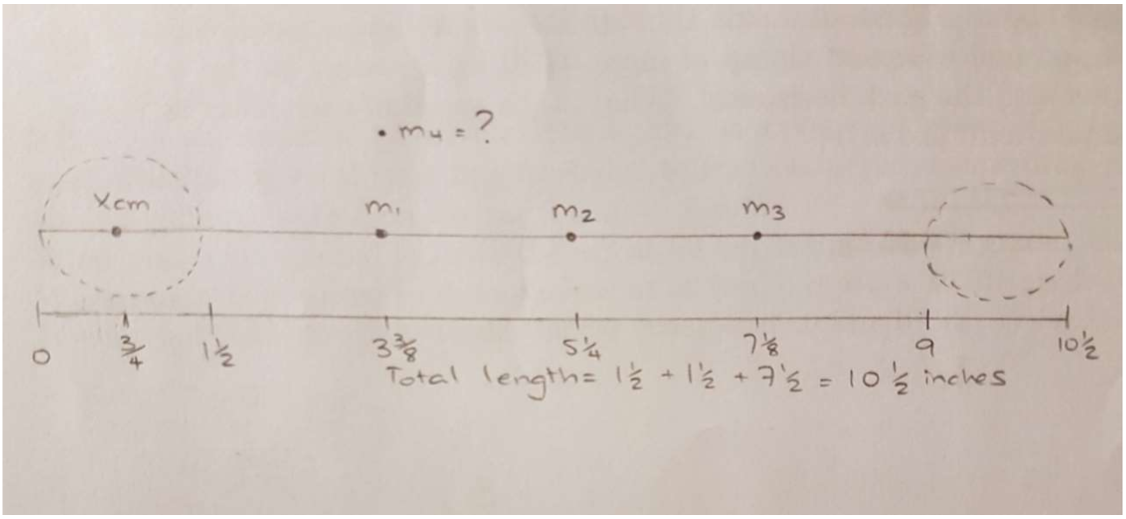

Figure 3: Centre of mass of the chassis from different contributing components along a horizontal axis.

Appendix C: Contributions from each team member

Name of Team Member	Individual Sections
Caroline	Selection of Route Conclusion Conflict due to Ethical Differences Propulsion System
Cristiano	Ethical Considerations Conflict due to Regulation Differences Levitation System
Sophia	Environmental and Social Impacts Conflict due to Cultural Differences Team Health Integration System
Sudipta	Stakeholders Financial Analysis Sexism in the Workplace Chassis System