ENGINEERING

McMaster University

Final Report

ENGINEER 2PX3 - Integrated Engineering Design Project 2

Tutorial T06

Self-Driving Team 18

Housam Alamour (400317089)

Mohamed Aly (400328781)

Allison Cook (400300768)

Kelly Deochand (400328918)

Submitted: April 14, 2022

Table of Contents

Academic Integrity Statement

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Housam Alamour (400317089)

X

Housam Alamour
Student

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Mohamed Aly (400328781)

X

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Allison Cook (400300768)

x

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Kelly Deochand (400328918)

Kelly D.

Executive Summary

As the popularity and urgency of self-driving cars increases, our roadway infrastructure can be improved through the utilization of the technological advantages of self-driving vehicles. However, this task comes with many challenges and has many stakeholders holding conflicting opinions, in addition to the constraints that must be considered related to the area such a solution would be implemented. Our solution is to design an improved self-driving intersection to be used in Ontario within the next 5 years that improves safety of intersections by decreasing accident rates and improves performance by increasing the number of vehicles that cross per week, while being a feasible design spatially that is scalable for different sized intersections.

Our team developed a Displaced Left Turn intersection to solve this problem. This intersection follows the general format of the 4-way cardinal intersection we are used to, however it diverts some traffic maneuvers so that they are not all taking place in the center of the intersection. Left turns are performed in a separate lane, where they can be performed more quickly, safely and frequently. As pictured in our final design section, the incoming left turning traffic will cross through a minor yielding intersection through oncoming traffic and perform a left turn from there.

To arrive at this design, our team utilized the PERSEID method, with major focus on the performance, environmental, regulatory, and socio-cultural layers. As stated in our problem definition, the design must improve throughput per intersection while also decreasing the number of fatalities per intersection (thus increasing safety). A crucial decision we made was to have this minor intersection be a yield left turn lane rather than a stoplight. We also decided early in the design process what tests we needed to perform in the simulation, and what we expect the results to be. These tests include adjusting the number of lanes, ratio of self-driving to human-driving vehicles on the road, as well as congestion levels. These categories to be tested will prove the design's ability to improve with the introduction of self-driving vehicles, perform well under high traffic times of day, as well as proving the scalability of the design.

Our team ultimately considered many different designs, all of which had their advantages in certain categories. Using the PERSEID method to organize how well each design achieved each category helped to determine that the displaced left turn intersection was the best overall performing design. While some others such as the cardinal directions design, One-way roads with U-turns, and two laned roundabouts all excelled in other categories. Along with that consideration, the acceptance among all roadway users was also heavily considered. In addition, the displaced left turn intersection was the fairest design for both human-driven and

self-driven vehicles. This was important for our team because fairness means that the road doesn't present any prejudice no matter the car you drive or what your wealth status is.

Overall, our team's approach to this problem mainly involves an infrastructural change that allows self-driving cars to have their technology widely used and benefit everyone who uses roadways by creating a safer intersection. Moving forward, it is worthwhile to consider more precisely how our design compares to current roadways, as our simulation is compared to a baseline meant to mimic current intersections. The next biggest step is to define liability of self-driving cars in legislation. Our team did develop a hierarchy of liability as well as some common laws that would improve the consistency of our design, but to implement these is a challenge we will tackle in the future. Moreover, we also planned to have a stakeholder's survey to see how widely accepted our design would be outside of our predictions.

Introduction

Commute times, stress on traffic infrastructure, climate impact, and roadway accidents are all problems that stem from current roadway infrastructure. According to the Ontario Ministry of Transportation, traffic volume and accident rates in Ontario have been steadily increasing every year for the past decade [1]. A major reason for this is current intersection designs have poor performance and safety characteristics and lack consideration for socio-economic concerns. All this stems from the wasted potential for improvement of intersections by using new and improved self-driving technologies. Our team set out to specify the problems caused by current intersections so that we could create a new, long-lasting intersection design that solves the issues plaguing modern roadways.

During our project we found that there was a wide variety of stakeholders for our project, all of which were collectively impacted by poor roadway intersection designs, and we also found that each of their problems falls under one of the PERSEID layers. The first groups stakeholders for this project were families who drive through the intersection and will be concerned with its safety. Some concerns that may be raised include: will families be safe travelling through the intersection? What are the possibilities of an accident? Will children be safe crossing the intersection as pedestrians? All these concerns fall under the socio-cultural layer and force our group to consider the impacts of our design on safety and accident rates of pedestrians and drivers alike. The second group of stakeholders for our design were commuters. Commuters will be using the intersection most often (especially during their 9 to 5 commutes) and, to add to this, they will be the group that often pushes our design to the limits during rush hour when the intersection will be used at max capacity with the largest number of cars. Thus, they will be one of our most important stakeholders in terms of testing our design under a wide variety of circumstances and input parameters. The next stakeholders to be considered were federal, provincial, and municipal government bodies, which are also vital to consider as they will be the gatekeepers to the success of the project. To start, they hold the final say in whether our design is accepted for implementation or not. Federal government will be concerned with the environmental impact of our design and how well it is accepted by the international community, such that it is easy to use by foreign commuters. Provincial governments will want the design to be economical to remain within budget and be quick to construct to avoid long road closures. Finally, municipal governments will control where exactly our design can be used and thus will want the design to be easy to implement in a wide variety of current and future intersection locations. Further, all these different levels of government will have to pass and revise laws and regulations surrounding current driving practices to better serve this new intersection design. Collectively these government stakeholders dictate the success and implementation of our design. They control the massive amount of funding the project will require, and they also control the laws and regulations that will become constraints to our design. Therefore, our group must work to satisfy the concerns of the government stakeholders the most with our design. There also exists some conflict between different stakeholders, such as self-driving car manufacturers and non-self-driving car manufacturers. The former may receive a performance advantage by our new design which will use self-driving technologies, creating an unfair disadvantage in the car manufacturing market. This interconnected web of different stakeholders and their wants, needs, and conflicts was thoroughly considered and evaluated by our team when developing our design to create a solution that best fits the problem at hand

Naturally, following this our team created a problem statement that sums up the concerns of all the stakeholders: We must design an improved self-driving intersection to be used in Ontario within the next 5 years that improves the safety of intersections by decreasing accident rates per week and improves performance by increasing the number of vehicles that cross per week.

Objectives and constraints on the Design

The first major objective of our design is to increase performance This was measured using the metric of number of cars that can travel through the intersection per week. This metric was chosen because the main objective of an intersection is to get as many cars through as possible in a safe manner. By measuring the number of cars that travel through in a week, we can account for the variations in traffic that may occur due to rush hour or increased traffic on weekdays versus weekends due to commuters. The second objective of our design was to increase safety. We decided to measure this by comparing the accident rate of our design for the current year to the accident rate of the previous year. The lower the rate compared to the previous year, the better the design. This metric was chosen because current trends indicate that accident rates on Canadian roadways are decreasing year over year according to the Government of Canada [2], and we want to continue this trend with our design to satisfy our stakeholders. Other aspects we must consider are the constraints on our design. The first of these is the amount of space our design takes up. Depending on where our intersection is implemented, there may be a limitation on space if it is placed in an area where real estate is at a premium such as a large city, buildings will be close to our design and so our design must be able to fit in these small spaces. In addition, our intersection may be deployed in areas of high traffic volume that require many large lanes. Thus, our design must be adaptable to this wide range of different situations. Another constraint is that our design must work for both self-driving and human-driven vehicles so as not to completely disrupt current road infrastructure and not give an unfair advantage to self-driving vehicles on the roadways. Cars travelling through our intersection must abide by speed limits and thus cannot travel at too fast of a speed, even if that may allow for increased performance and so our design must consider this speed limit depending on where it is implemented. Finally, our design must not impede the crossing of pedestrians and must take handicapped pedestrians into consideration by implementing design features that make it easier for them to cross.

Scope of the Report

The objective of this report is to document the design process of our solution to the self-driving intersection problem. We begin by introducing the initial designs the team came up with in the first five weeks of the project and then exploring the details, strengths, and weaknesses of each of these designs. We then move on to describe how we iterated through these designs while also developing new designs throughout the next weeks. Once the top designs are presented, we show how we used the decision matrix as well as group discussions to pick the top overall design. Following this we describe the final design and present diagrams to point out specific design choices we made and discuss how the design meets the objectives and constraints we set. Finally, we end the report with a conclusion that explains the future of this design as well the collective reflections of the team and what we learned throughout working on this project.

Conceptual Design

Design 1 - Distinct Roadways for Each Direction

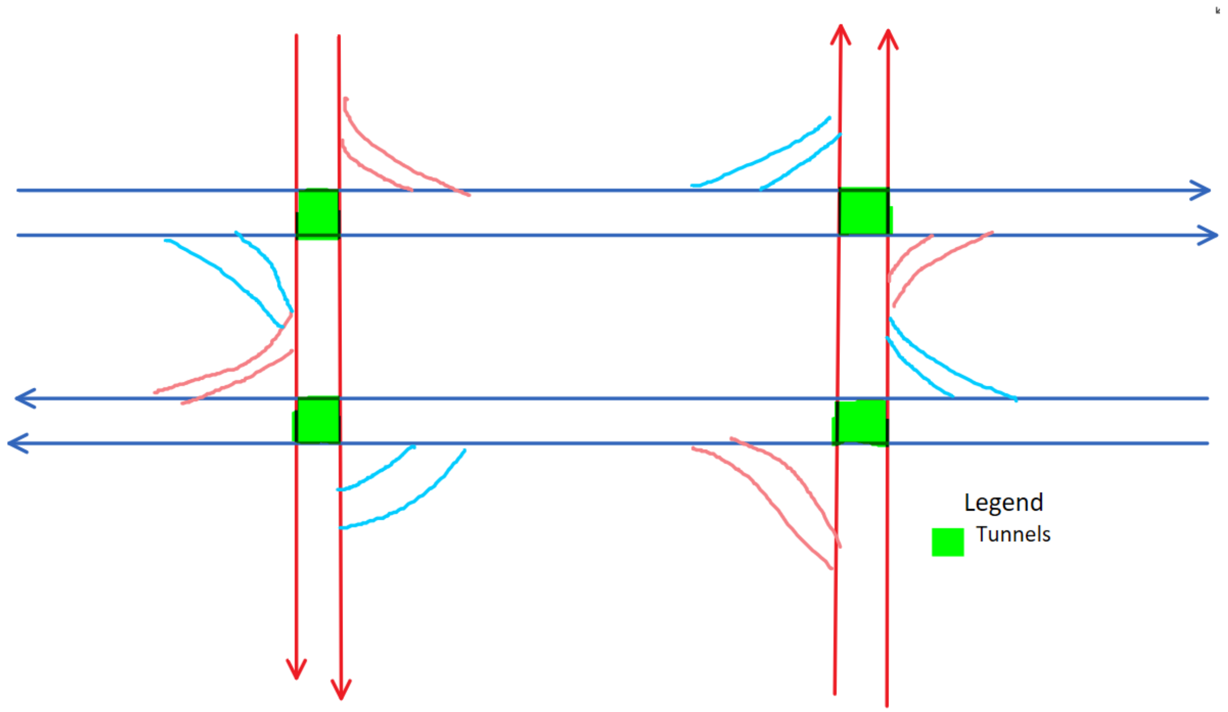

Figure 1: Distinct Roadways for Each Direction Design

Design Evaluation

This design had many strengths, especially excelling in terms of performance. It completely eliminates the need to stop with the exception of vehicles that yield when making a turn, and so throughput measured by the amount of vehicles crossing the intersection is maximized. This can also increase performance for pedestrians crossing the intersection. With this increased throughput, we can afford to make the signal for pedestrian-crossing last longer and allow more pedestrians to cross in a single light cycle. Another important aspect is that it eliminates the possibility of head-on collisions, which account for 55% of accidents and the most deaths [3].

While this design's strengths may be convincing, there are some challenges that make it difficult to implement. When it comes to performance, the main weakness comes from the possibility of blockages occurring on the onramps. If two major roadways cross, an onramp of people attempting to make a right-hand turn may become overcrowded and extend onto the main road, causing traffic slowdowns. Assuming every car was self-driving, this problem would be more easily solvable, but that will not be the case for a long period of time. Another challenge this design faces is regulatory issues. This design requires a lot of construction and excavation, thus requiring a large amount of funding from the government. One other issue is that current zoning laws require a certain number of entrances, exits, and parking spaces on the roads in front of residential and commercial buildings, and this design may have difficulties meeting these requirements. Lastly, this design would be difficult to scale and fit into different areas such as in the middle of a city.

Design 2 – Two Lane Roundabout

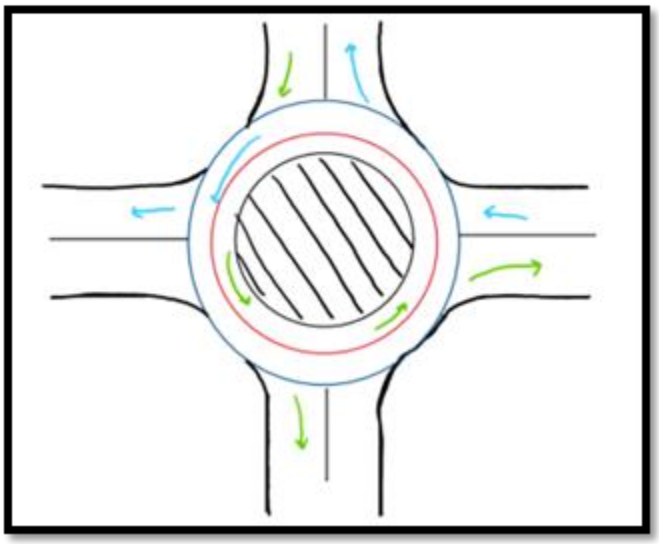

Figure 2: Two Lane Roundabout Design

Design Evaluation

We found that this design had decent balance when comparing different criteria. From a performance perspective, it provides a constant flow of traffic, with stopping only when attempting to enter the roundabout. From a safety perspective, it eliminates the directions leading to T-bone and head-on crashes. However, there are also some safety concerns. For example, roundabouts are quite infrequent, and so a sudden increase in roundabouts may be too drastic of a change. This may in turn cause people to crash if they do not know how to traverse roundabouts well. Another safety concern would be for pedestrians, as crossing through a roundabout will be a different experience from what they are accustomed to. The pedestrian lights may also cause a large amount of traffic slowdown in the roundabout itself, which would not only impact the performance one direction of the intersection, but all four different directions attempting to enter it. Lastly, similar to the Distinct Roadways design, this design requires a large amount of new construction and would be difficult to scale and implement in certain scenarios, such as a small busy city intersection.

Design 3 – U-Turn Roads

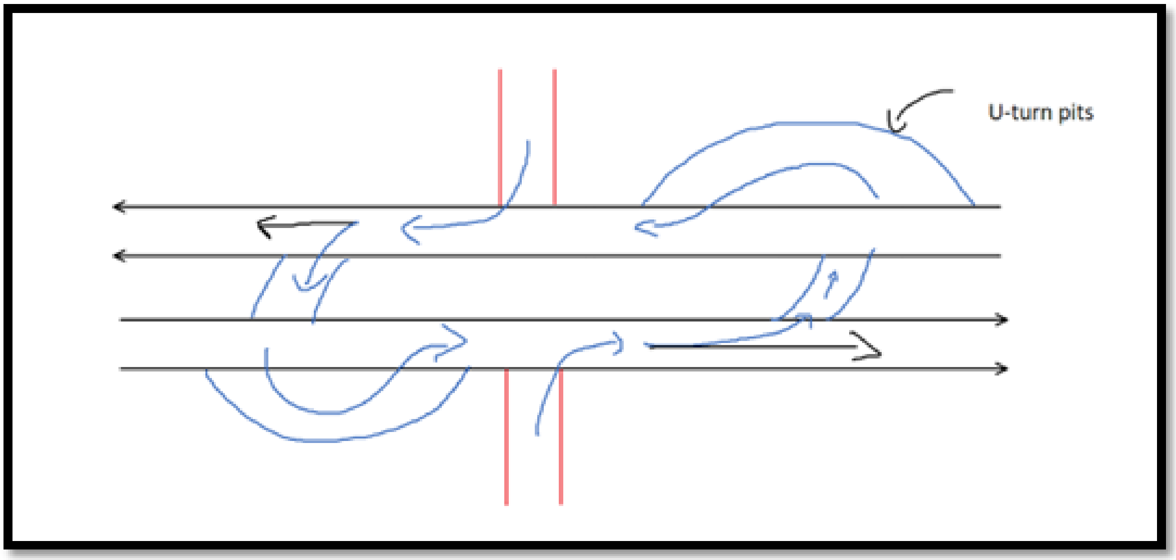

Figure 3: U-Turn Roads Design

Design Evaluation

In terms of performance, this design also does well. It eliminates the need for signals or any traffic management system and so vehicles on the major road never need to stop. This significantly increases the number of vehicles that can travel through the intersection. From a safety perspective, this design eliminates T-bone crashes that can occur between vehicles travelling in perpendicular directions, which accounts for “25% of car accidents in Ontario” [4]. Besides this, the design would also be a lot easier and cheaper to implement than the previous two mentioned, as it requires less construction. The only requirements would be closing the middle intersection, and the addition of the U-turn pits. Regulation will also be simple for this design. Since the only thing this design implements are U-turn pits, very little changes need to be made in order to integrate it into current laws.

This design also comes with some drawbacks, such as the fact that vehicles travelling on the minor road have their travel time significantly increased, especially when trying to turn left or go straight. This concern is not detrimental to the design, though, as we expect the minor road to have less traffic overall compared to the major road. From a socioeconomic perspective, another drawback may be the acceptance. This design is more confusing than what is currently available, and so a huge overhaul may be too drastic of a change. After implementation, they also would be very unsure how to use it.

Decision matrix

Criteria	Weight	Design 1: U-turn roads		Design 2: Displaced left turns		Design 3: Two-lane roundabout		Design 4: Cardinal directions	
Performance (throughput)	4	Score: 7	Total: 28	Score: 7	Total: 28	Score: 8	Total: 32	Score: 9	Total: 36
Acceptance Drivers (socio-cultural)	3	7	21	4	12	5	15	8	24
Acceptance Pedestrians (socio-cultural)	3	4	12	8	24	9	27	8	24
Safety (socio-cultural)	6	6	36	6	36	8	48	8	40
Regulation (meets laws or easy to change)	2	8	16	5	10	8	16	3	6
Greenhouse gas Emissions (environmental)	5	5	25	6	30	8	40	5	25
Construction (environmental)	1	8	8	6	6	7	7	2	2
Total	-	-	146	-	146	-	185	-	157

Table 1: decision matrix – design studio 9

In the decision matrix, the Two-Lane Roundabout design scored the highest. It is a good design, however, as we stated in the design evaluation, we found that it is not really a scalable design that you can begin implementing in many different locations. It also does not have many more options for optimization. The second highest score was the Distinct Roadways for Each Direction design. However, while it performed well in certain aspects, there is one barrier that was too large to ignore. This design is too ambitious and would require far too much new construction to be implemented. It would also not be deployable in many areas, such as a busy city intersection, and would be more costly to build and maintain. While the two other designs tied for the lowest score, we found that the U-Turn Roads and Displaced Left Turns designs were the most feasible and realistic. We considered scalability, road user acceptance, and PERSEID criteria, and ultimately decided to pursue the Displaced Left Turns design.

Final Proposed Design

Description of the Final Design and How it Works

The final design decided upon, the displaced left turn, best met objectives, constraints, and the other considerations of feasibility, scalability, and usability of the design. It consists of a major intersection, made of four directions with opposing traffic, with activity-level measuring traffic light, and additional left turn lanes that diverts drivers from the main intersection. Instead of turning at the intersection, the displaced left-hand turn has a vehicle cross on-coming traffic at the yield intersection before entering the second half of the lane to finish the turn. With this the design increases the throughput of traffic as it simultaneously allows for the continuous flow of traffic in the main intersection and decreases the number of cars that are required to stop.

Design Choices & Justification

The numerous design choices made through our design iterations correspond to different PERSEID layers explored during the design studios, performance, socio-cultural, regulation, and environmental. The intersection was designed to maintain a similarity to a traditional intersection to appease the socio-cultural aspects of acceptance of the design to increase the use of the intersection. Additionally, it addresses the other users of the road such as accounting for cyclists and pedestrians to also use the intersection. The yield for the secondary intersection was selected to allow for the access to the self-driving features of the technology being able to calculate and respond to the situation faster than human drivers.

The displaced left turned lanes address regulatory concerns, performance, socio-cultural and environmental. The left turn allows for human-driven vehicles to act as self-driving vehicles. Safely, it allows for the vehicles to focus on crossing the oncoming traffic before having to consider pedestrians. This presents drivers with increased visibility of the pedestrian’s crossings. The design also is not drastically different in design to current road regulation; thusthus, most road regulations are met by the design. The addition of the displaced left turn lane can be added onto existing intersections and does not take up more construction time and resources than traditional intersections.

Final drawings

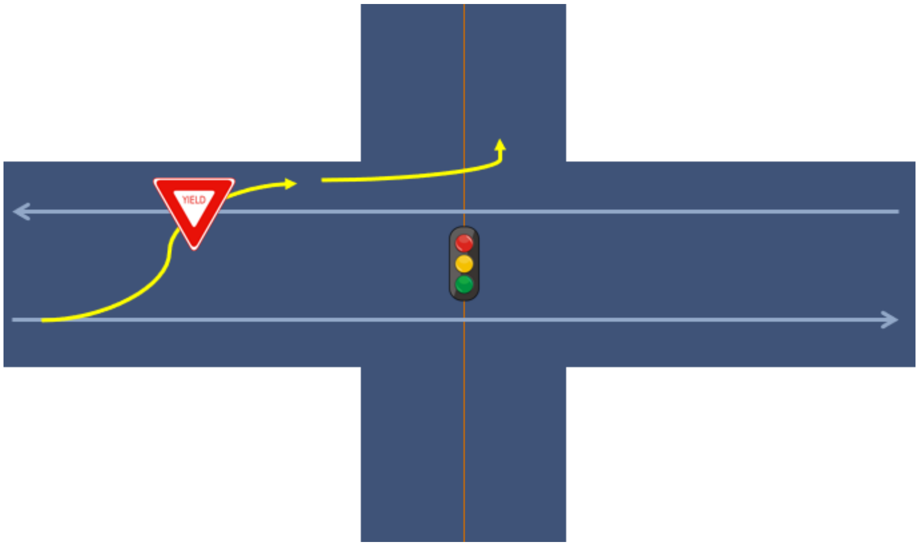

Figure 4: A simplistic representation of the displaced left turn design

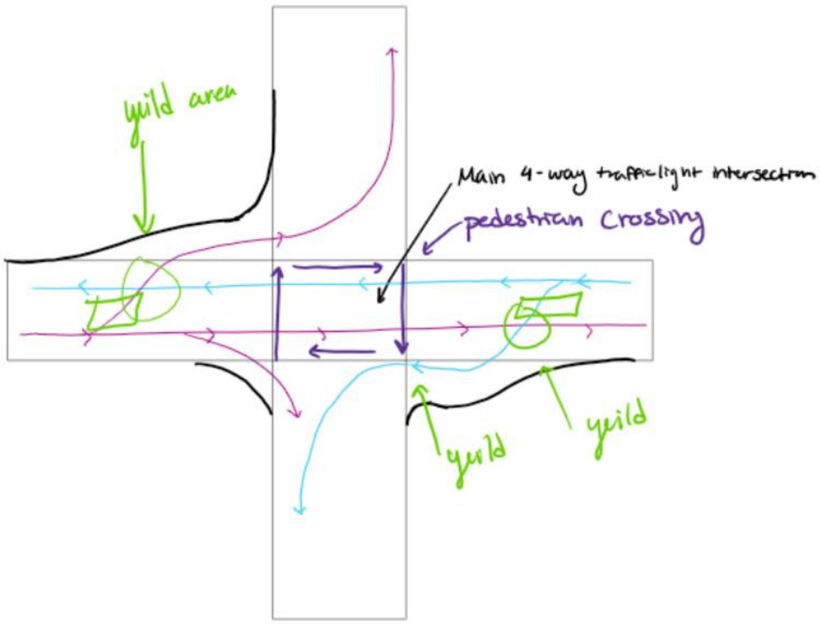

Figure 5: An image of the initial Displaced left turn design

Discussion of Objectives & Constraints Met

The objectives for the intersection were, to increase performance, decrease the accident rate, reduce emissions, increase fuel economy, limit vehicle congestion. The metrics used for the measurement of the objectives are based on actual implementation, with the increased performance being the only objective that could be demonstrated with the simulation. The measurement of the first objective was done by measuring how many cars travelled through the intersection per week. Measurement of the second objective was done by comparing road accident rates of the new intersection with accidents in the previous year. Measurement of the third was to compare the emissions of cars while driving through the intersection. Measurement of the fourth, increase in fuel economy, was measured in how many litres (or watts) used per kilometer. Measurement of the fifth, number of cars per meter squared of the road.

This design is verified to meet the only confirmable objectives, the increase in performance to a traditional intersection and the limit of congestion, as shown in the simulation. It also increases performance and lowers the time spent with large amount of congestion when more self-driving vehicles are on the road than human-drivers. The other objectives can be estimated based on the throughput and time of the vehicles such as emissions, and fuel economy and since there is increases throughput and less time spent idling and stopping or starting, we can infer that these objectives have also been met. The decreasing of accidents rates is untested because the simulation does not account for possible collisions, however, with the increase of self-driving cars and the reduction of crossing traffic the assumption would be lower accident rates but human-drivers with their emotions and distraction are unpredictable.

Notable constraints that are considered in this design would be space, the potential to favour self-driving vehicles, and enabling pedestrians to cross. In urban settings where space is scarcer, and real estate is more highly valued, a large intersection such as this might be a limitation on implementing this design. Therefore, the design should be adaptable to ensure maximum situational utility. Moreover, the design should consider whether it favours the movement and flow of self-driving vehicles. Mitigating this concern might be accomplished by ensuring that vehicles passing through the intersections abide by speed regulations, even at the cost of efficiency of the intersections design. Further the speed limit of this intersection should consider both self-driving and conventional vehicles. The final constraint is the ability of pedestrians to navigate the intersection. This design addresses the above constraints through the design choices made above and are used as the justification

Simulation Results

To begin, we want to ensure proper sanity checks for our simulation to ensure that our simulation and by extension our design is preforming as we expect it to. This starts outside of the simulation by doing research into current intersections and establishing how many cars we would expect to cross through our intersection in a single cycle. After some research, we could not find comprehensive results on how many cars travel through an intersection in one cycle because of the wide variety of factors that differ between intersection such as number of lanes and congestion. However, by extrapolating data from Stats Canada "Canadian Motor Vehicle Statistics" [2], we were able to estimate that for an intersection that has two lanes, an average amount of congestion no self-driving cars and a cycle time of 60 seconds, 10 cars could cross through in one cycle. Our team established that if there is a very low amount of congestion, the number of cars that pass through will be low because there are not many cars to pass through. The number of cars passing through will increase in relation to congestion up until about 50% congestion, after which it will begin to decrease due to slowdowns in traffic. We also established that the more self-driving cars, the faster our simulation should run because of the dedicated left turn lanes, and that more lanes will allow more cars to go thorough because of the increased throughput they allow as each lane acts as a dedicated path for cars to go through. These findings will be used as our baseline numbers that we will compare all our other simulations to, and it will act as our sanity check to make sure the data we are getting from our simulation makes sense and give us confidence in our results.

After establishing this preliminary baseline, we began conducting our test. We started with a test to mimic our baseline to act as a sanity check. From this, we found that our design performed better than expected with 12 cars getting through due to our dedicated left turn lane which allows cars to turn left when otherwise they would not be able to.

The next test we ran was the same as the baseline, but we have 50% of the cars be self-driving. When we did this, we saw a 25% increase in our performance compared to baseline, with 15 cars getting through. The explanation for this is that human drivers have a slower reaction time than self-driver cars, and thus can get through the intersection faster. Another reason for this increase is that self-driving cars can travel more closely together thanks to their improved safety and collision detection systems and sensors that prevent rear end collisions. Thus, they can travel more tightly together, allowing more self-driving cars to travel through at once. Finally, our self-driving cars using our dedicated left turn lane can detect more safe opportunities to turn left thanks to their sensors and increased visibility, thus more self-driving cars allow for more cars turning left. In our simulation, we account for all these differences and thus they show up in our output. We followed this up with a similar test of 100% self-driving, which gave us 20 cars crossed resulting in a 33% boost. The reason for the bigger jump in performance from 50-100 compared to 0-50 percent self-driving is that if all the cars are self-driving, we eliminate all possibilities for human error in our design. Whereas if there are still some human drivers, they will make some small mistakes such as having a slow reaction time that disrupts the perfect flow of traffic achieved by a fully self-driving system.

Following this we had a test to simulate the intersection at 100% congestion, which evidently resulted in slowdowns due to cars overloading in the lanes and intersection as cars pile up and stalled to wait for clearings, especially for cars trying to use our displaced left turn lanes. The results showed only 10 cars going through, which is a 16% decrease and interestingly exactly mimics our expectations for a regular intersection, showing that even at full capacity our design preforms as well as a regular intersection under normal conditions. This pointed out a **limitation** of our design, that the left turn lane stops being effective if the lanes are too congested. One way to avoid this limitation is to create a strip of the lane that is a “no stop” zone, such that cars cannot stop and block the left turn lane allowing it to always be open.

The following test entailed the same inputs as our baseline but with the number of lanes in each direction increased to 4. This resulted in a massive increase of 125%, which was expected as stated in the sanity check where the more lanes we have the more cars can go through. This test helps us simulate a large intersection such as in an urban setting versus a small single lane intersection such as in a rural setting. This also helps our simulation achieve the objective of being adaptable to different situations.

We also ran a few tests to check how our simulation runs when we have a low amount of congestion at 25% and this reflected our expectations with only 5 cars getting though.

One interesting and novel insight we noticed from our results is that the more self-driving cars we have, the less greenhouse gas emission our intersection produced overall in kilograms per car crossed. This is due to the self-driving cars spending less time idling as compared to human driven vehicles because of slow reaction times, in addition to them being able to wait for less time to find a safe left turning opportunity, and because they can travel more closely together.

These tests thus gave us high confidence in all our result because they all conform to the expectations, we outlined in our sanity checks. We can be safe rest assured that our design will perform as we expect it to, and we can present this the data collected from the simulation to stakeholders such as government bodies to inform them about the improvements in performance they can achieve without design.

Some future tests we can run on our simulation are having the cars cross the intersection in a shorter amount of time and decreasing the time it takes for them to stop, both of which we would expect to increase our performance. We may also want to control the rate of cars crossing that turn left to see how well our dedicated left turn lane handles a higher amount of traffic. The simulation may also be expanded by adding more attributes to the car class as discussed previously and the direction class can add lanes different types of lanes such as HOV lanes, bike lanes, to allow for adaptability to different environments.

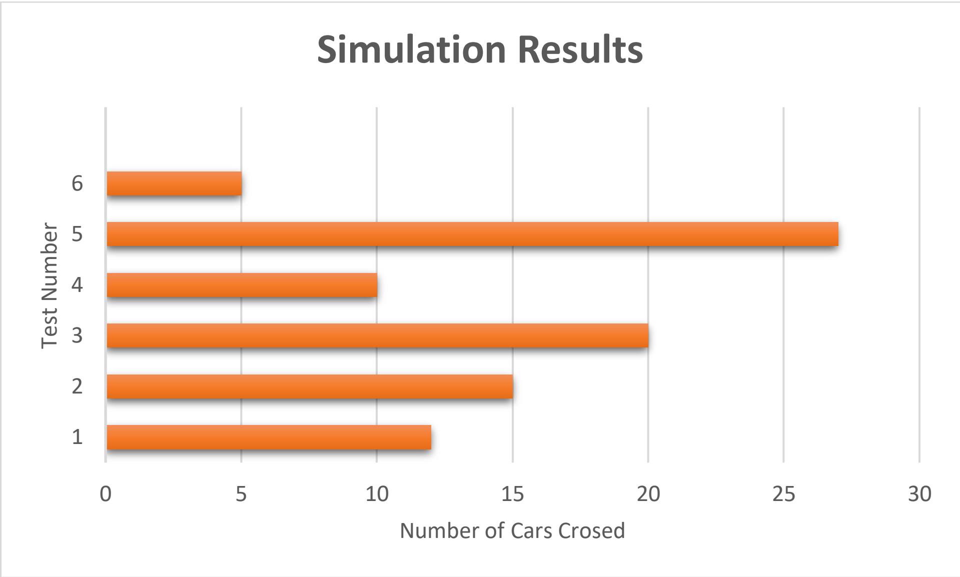

Figure 6: Graph of simulation Results

Test Number	Congestion (%)	Self-Driving (%)	Number of lanes	Amount of Cars crossed
1	50%	0	2	12
2	50%	50%	2	15
3	50%	100%	2	20
4	100%	50%	2	10
5	50%	50%	4	27
6	25%	50%	2	5

Table 2: Table of Simulation Results and respective inputs

Amount of Cars crossed	Pollution per Car crossed (kg /car)
12	3
15	3.75
20	5
10	2.5
27	6.75
5	1.25

Table 3: Table of Simulation Results comparing amount of cars crossed to amount of pollution created

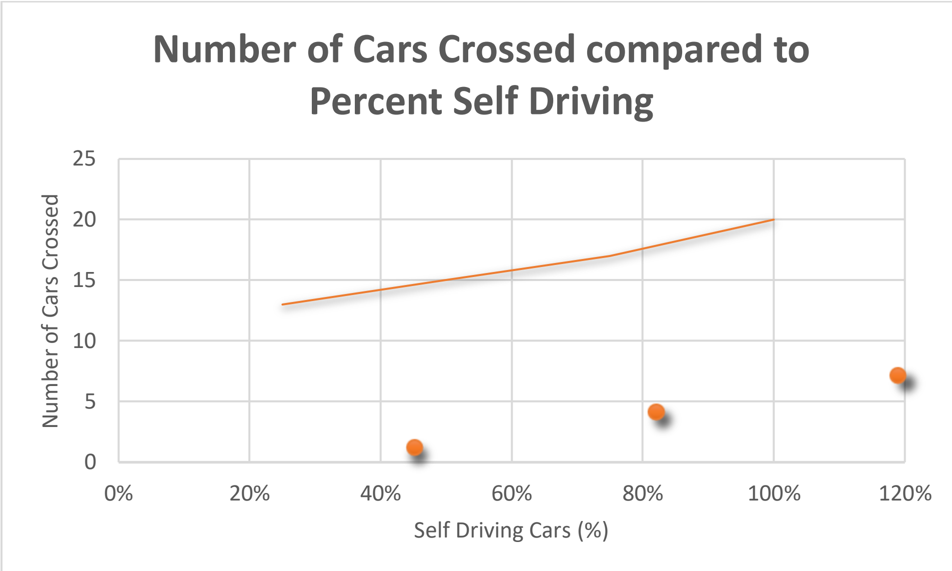

Figure 7: Graph showing relation between percent self driving and number of cars crossed (all at 50% congestion)

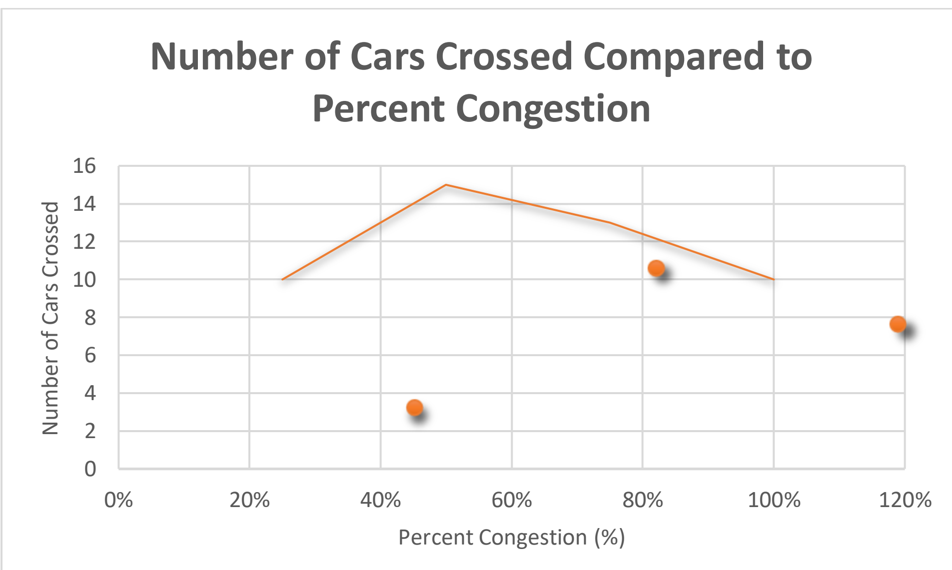

Figure 8: Graph showing relation between percent congestion and number of cars crossed (all at 50% self-driving)

Conclusion

In conclusion, our displaced left turn design is proven through a variety of simulations to increase throughput of the intersection according to our baseline. Despite the design being well developed in the four PERSEID layers we focussed on, there are still many improvements and further refinements to consider. For instance, analysis of fatalities was difficult to interpret from our simulation. With more time, our team could develop a traffic model prediction simulation with some key features from the model predicted for use in developing countries where traffic fatality data is hard to come by [5]. This model heavily acknowledges the relationships of income level per capita with road traffic mortality whereas our tea focussed on the how income level affects the car the average person may drive, and our design aims to create fairness among all roadway users [5].

Given more time, we would also create a simulation that accounts for pedestrians and cyclists to provide proof of concept for their gain. In addition, the concern of wider vehicles being able to make the tighter left turn was brought up to us, and with more time we can perform model-based simulations with different types of freight vehicles to ensure the dimensions don't prohibit any necessary traffic. Another important aspect that can be better developed with time and research is the liability and implementation of proposed regulations. Our team developed a hierarchy of who is liable in the event of each possible combination of crash, but this requires cooperation from car companies and insurance companies. To properly understand how viable our developed solution to the liabilities and regulations, we would need to present this idea and receive feedback to improve it from there. And in terms of environmental consideration, with more time we can try to simulate vehicle emissions that reflect the rate of acceleration and deceleration, as well as with varying fuel economies to depict different ratios of self-driving to human-driving vehicles.

In terms of the design process, our team learned through this project the importance of grouping our critiques into the four PERSEID layers we focussed on rather than having less structured discussions. This was especially handy in understanding exactly how each layer impacted our stakeholders and how trade-offs between layers developed. We also learned the importance of constantly reviewing our goals. Our team often conducted new research and developed each idea further, but when the time came to decide which one design to pursue, we all found that the designs were overall good due to us constantly ensuring the design met our main goals. In the future, these skills will help us succeed in lengthier projects where it may be easier to drift away from our goals. The PERSEID method also helped us subconsciously consider some factors that may be overlooked since we are learning, but a professional engineer would notice. This includes some of the regulatory concepts we developed, such as the liabilities and fundamental laws, which further advance our design.

With respect to team dynamics, our team learned how challenging it can be to arrange time now that we are all in our specialized programs and have different schedules. We learned the importance of planning and communication in a new sense than in the past, and these skills will translate well to a future workplace where perhaps different departments must communicate and work towards deadlines together. In the future if we were to work together again, we would challenge ourselves to provide more constrictive feedback to each other throughout the design process. While we were not shy to critique one another’s ideas, the major revisions occurred a bit later than they could have and for this reason were sightly rushed. To have discussions about each idea, which were often small additions to a larger schemed intersection, we would have more time to perform further research and develop our design.

Lastly, the design process was well structured for this project as with previous experience we were able to subconsciously apply the cycle of defining, identifying, brainstorming, selecting, prototyping, testing, iterating, and communicating. While we were prompted early on to consider methods in which we want to design our simulation and parameters for it, it would have been beneficial to either be given a more specific simulation that gives us more new data. These slight changes would allow us to get more valuable information about how each design performs, without having to spend the time making simulations for designs we wouldn’t pursue in the future.

References

[1] "Commercial vehicle survey," *MTO iCorridor*. [Online]. Available: https://icorridor-mto-on-ca.hub.arcgis.com/pages/cvs. [Accessed: 12-Apr-2022].

[2] Transport Canada, "Canadian Motor Vehicle Traffic Collision Statistics: 2020," *Transport Canada*, 01-Feb-2022. [Online]. Available: https://tc.canada.ca/en/road-transportation/statistics-data/canadian-motor-vehicle-traffic-collision-statistics-2020. [Accessed: 12-Apr-2022].

[3] "Rural Transportation Statistics," *Rural Transportation Statistics | Bureau of Transportation Statistics*, 16-Nov-2021. [Online]. Available: https://www.bts.gov/rural. [Accessed: 13-Apr-2022].

[4] M. Lalande, "T-Bone Collisions," *Lalande Personal Injury Lawyers*, 10-Aug-2021. [Online]. Available: https://injured.ca/t-bone-collisions/. [Accessed: 13-Apr-2022].

[5] M. J. Koornstra, "Prediction of traffic fatalities and prospects for mobility becoming sustainable-safe," *Sadhana*, vol. 32, no. 4, pp. 365–395, Aug. 2007. [Accessed: 14-Apr-2022].

Appendix

Data

Test Number	Congestion (%)	Self-Driving (%)	Number of lanes	Amount of Cars crossed	Pollution per Car crossed (kg /car)
1	50%	0	2	12	3
2	50%	50%	2	15	3.75
3	50%	100%	2	20	5
4	100%	50%	2	10	2.5
5	50%	50%	4	27	6.75
6	25%	50%	2	5	1.25
graph 2					
1	25%	25%	2	13	0
2	50%	50%	2	15	0
3	75%	75%	2	17	0
4	100%	100%	2	20	0
5	50%	50%	4	27	0
6	25%	50%	2	5	0
graph 3					
1	25%	25%	2	10	0
2	50%	50%	2	15	0
3	75%	75%	2	13	0
4	100%	100%	2	10	0
5	50%	50%	4	27	0
6	25%	50%	2	5	0

Simulation Description

For our simulation, we created a Java program that runs virtual cycles of the intersection. The program structure follows object-oriented design principles, using classes to separate the different aspects of the simulation. To start, we have a class representing cars with various attributes represented by variables including the Boolean selfDriving to indicate whether this car is self driving, timeToCross which represents the time it takes the car to cross the intersection and is corelated with the speed of the car, reactionTime that is used for the delay between the light switching states and the car moving, emissions per kilometer among others. These variables define each car on the road and can be switched depending on the type of car we want to simulate. Further, the use of a class allows for easy maintenance and expansion of the code later on by adding more attributes to the cars such as class (sedan, truck, etc.), dimensions, weight which could be used when considering material choices for the design, for example if the design is being built on an overpass bridge and can only support a specific weight load. Also, we may also add fuel economy for each car in order to assess the environmental impact of the intersection by collecting data over a period of time. This and many other additions may be made to upgrade this simulation and allow it to accurately assess different qualities and quantities of the design while acclimating as the design changes and is implemented in different locations with different needs.

Instances of these cars are generated and then used in an instance of the Lane class. A lane is a queue of cars, which simulates a real lane well because of the first in first out property of queues which allows cars that are added first to cross first. The lane has methods to add a self driving car and human driven cars by generating one respectively and then enqueuing it and to make the first vehicle in the queue cross by dequeuing. The simulation also has a SignalLight class that simulates the traffic light running through stop and go cycles for each respective direction. It does this by keeping an array representing the 4 cardinal directions and representing a green light with 1 and a red light with a 0.

The simulation represents multiple lanes going in the same direction using the Direction class, which is an array of lanes. This class can add lanes depending on the size of the intersection and may also have different a different number of lanes for each direction. This helps our design satisfy the adaptability objective we outlined in the introduction, as now our simulation can easily show how our design would perform depending on the size of the intersection. It also has the most important aspect of our design, the dedicated left turn lane which acts as a special type of lane that allows cars to cross through independent of the light. Finally, we have the Cycle class and subCycle method. These are the main running components of the code and what are used to run a simulation. The Cycle class has attributes for the cycle time, representing how long we want each light cycle to last for our simulation. We also have attributes for percent congestion and percent self driving to simulate a variety of congestion rates and amount of self driving cars in our intersection. The cycle class constructor runs first, generating 4 directions each with their respective number of lanes, then generates a signal light. The cycle class can then generate a batch of cars, which uses the percent congestion and percent self driving attributes to generate a random combined batch of human and self driven cars. Finally, we have the subCycle method which runs one light cycle of the simulation. It generates cars for each respective direction then allows cars through depending on the state of the traffic signal using if and for loops. Once a certain number of subCycles runs, we can use methods to return the total time passed for the cycle, the total number of cars crossed, and the number of emissions produced. This data will be essential to the analysis of our design under different conditions, constraints, and inputs.

Design Studio Worksheets

Week 2: Synchronous Design Studio

Team Building and Lessons Learned

Stage 1: Team Charter

As you are getting started to work on your project, one of the very first steps is to create a team charter. A team charter is a document that outlines the purpose of your team (i.e. your end goal), as well as detailed information about the team members.

Please list all the team members' information below.

Member	Full name	Preferred name	Email
Team Member 1	Kelly Deochand	Kelly	Deochank@mcmaster.ca
Team Member 2	Allison Cook	Allison	cooka27@mcmaster.ca
Team Member 3	Mohamed Aly	Mohamed	alym10@mcmaster.ca
Team Member 4	Housam Alamour	Housam	Alamourh@mcmaster.ca

Take a picture of your team. Be creative! Paste your team portrait below.

In a few sentences, please describe your team's goal for ENGINEER 2PX3 and what you are aiming to achieve.

Our team's goal for 2PX3 is to apply our new program specific skills to create a viable solution to our prompt. We would also like to use the PERSEID method to explore new aspects of problem solving.

Please outline 3 strengths for **team member 1** with one example or specific experience for each.

Strength	Example
Team collaboration	I find working in teams motivating, for instance P3 of 1P13 was a new challenge for me but really enjoyed collaborating on it.
Data analytics	I have some experience with MATLAB and different methods of representing data from CHEMENG 2E04 – Numerical methods class.
Interdisciplinary coursework	Coursework in biology, chemistry, anatomy, along with core engineering and chemical engineering courses such as fluid mechanics.

Please outline one area of improvement for **team member 1**.

Indecisiveness

Please outline 3 strengths for **team member 2** with one example or specific experience for each.

Strength	Example
Programming Skills	Specific courses, 2OP3 and 2XC3 taken last semester helped develop my object-oriented programming skills in java and progressed my understanding of C.
Organized	This year I'm working as the VP Finance for MMT. I need to keep well-organized records of money coming in and out of the club and correctly file the proper reimbursement and purchase orders.
Detail-oriented	A detailed focus view is essential in coding, discrete math, and logic areas, as a tiny logic or syntax error can ruin the whole problem. These are significant areas of focus within software engineering, so I've developed a great eye for detail.

Please outline one area of improvement for **team member 2**.

Procrastination, I will always get the work done on time, I just might end up leaving it to the last possible moment, which normally means the work complete isn't always the best.

Please outline 3 strengths for **team member 3** with one example or specific experience for each.

Strength	Example
Organization	I always update my to-do list to not miss assignments. I also have folders for each course so that the content is easily accessible.
Creativity	Coming up with a creative solution for our final project in 1P13 where we had to design a tool to help a person with a physical disability hold small objects
Planning	I like to be a part of the initial planning process not just in projects, but in most aspects of my life. If you are behind the plan, it is easier to understand and easier to work.

Please outline one area of improvement for **team member 3**.

I can always be more cooperative and help my teammates more, instead of only doing my part and waiting for everyone to finish theirs.

Please outline 3 strengths for **team member 4** with one example or specific experience for each.

Strength	Example
Time Management	I always create a Calander to keep track of my monthly school deadlines and create a daily planner to plan my days by the hour to stay productive
Research	In 1P13 I was always able to find strong sources pertaining to the subject matter which we needed to research.
Verification	I am very good at revising and going over previous work to check for mistakes and areas for improvement. For example, in 1P13 I was able to find the errors in my teammates code for the first design project and get our robotic arm working.

Please outline one area of improvement for **team member 4**.

I can help find areas of improvement among my teammates by noticing their mistakes and giving them constructive feedback on how they can improve.

Lastly, please outline the order of student presentations of your team.

Week	Member(s)
Weeks 3 and 7 *	Kelly Deochand
Weeks 4 and 8	Housam Alamour
Weeks 5 and 9	Mohamed Aly
Weeks 6 and 10	Allison Cook
Which Group are you paired with? Group 11 (Source water monitoring)	

Stage 2: EDI

Have you ever been on a team and felt like you weren't being heard? Alternatively, maybe your role in teams has usually been one of directing the group's work. If you have been in either situation, it may be time for a change. Go through the activities on Avenue to Learn under [4-Design Studios → Week 2 → EDI]

Personal Journal

1. Ensure everyone has an equal opportunity to share their thoughts and ideas by communicating with every member of the group.
2. Support one another and offer help if we notice someone needs assistance with anything.
3. Create personal connections with the people we work and study alongside to better understand them.

Stage 3: Project Activity #1

Each of the 4 projects in this course were chosen because they highlight the interdisciplinary concepts between the different fields. With this in mind, each engineer interprets a problem and creates objective and constraints based on their experience and background. In this activity, you will be learning about your team members' disciplines and how it impacts your project.

Please state your project, the disciplines it focuses on and the specific aspects of each discipline (e.g., Electrical Engineering - Electromagnetics, Mechanical Engineering – CAD, etc.)

Project: Infrastructure for Self-Driving Vehicles			
	Field 1	Field 2	Field 3 (Optional)
Discipline	Software Engineering	Civil Engineering	
Aspect	Developing the self-driving software, formal logic	The planning, designing, construction, and longevity of roadways that are essential to society	

For the next table, each member should come up with a technical performance constraint in each field.

Field 1	Field 2	Field 3 (Optional)
Memory capacity of self-driving cars	Road width	
Processing speeds	Max speeds cars can reach	
Amount of data collected	Braking power of the cars	
Capacity (of cars)	Size of the cars (length, width)	

As a team, discuss the technical constraints and decide on one important constraint per field. Make sure you justify your reasoning.

Field 1	Field 2	Field 3 (Optional)
Processing speeds	Braking power of the cars	

Justification:
Processing speeds and braking power are critical to the safety of the self-driving vehicle infrastructure. Processing speeds will decide the reaction time and braking power of the car will dictate how long it takes to perform the required stop.

The rest of the PERSEID layers include Environmental, Regulatory, and Socio-cultural constraints. As a team, brainstorm on the constraints that correspond to these layers and are relevant to your project. Make sure you justify your reasoning.

Layer	Constraint
Environmental	Lower carbon footprint than current infrastructure (less gas, sshorter trips, etc.)
Regulatory	All aspects of the project must meet regulatory and legislature needs
Socio-cultural	Societies willingness to use self-driving vehicles, making the infrastructure user-friendly for all drivers

Justification:
1. The system has a necessity to perform better than the current system to gain social acceptance. It is also a way to measure if the system will positively affect traffic, time spent driving, number of collisions, based on the amount of waste produced.
2. There are regulations and legislation in place for the safety of drivers, pedestrians, cyclists, and other vehicles. These must be followed in order to meet the comfort zone of people who currently use roadways. Examples of regulations include speed limits, use of back-up cameras, turning signals.
3. Society must be willing to adopt the new system if it is to succeed. If only a small amount of people begins to use the self-driving cars, there will be too many random variables around them for them to function with high efficiency.

Week 3: Synchronous Design Studio

Self-Driving Infrastructure Project

System Definition

Overview and Goals

- Review and discuss your stakeholder analysis

- Explore what aspects of current designs are appealing and frustrating. Do these qualities stem form the underlying design, drivers, or both?

- Brainstorm what makes a design “bad”. Or more precisely, what must be true about two designs to make one better than the other?

- Decide as a group whether to design a stretch of highway or an intersection

In the asynchronous activity this week you were asked to ponder and explore different stakeholders to this project. Compare your answers with your teammates. Record the aggregate of your individual work in the table below. Once complete, try to brainstorm 5 or so more as a group. This will help you when it comes time to complete Milestone 1.

For primary and secondary concern, list one of: Performance, Environmental, Socio-Cultural or Regulatory. If you feel there is no secondary concern, leave it blank.

Stakeholder	**Primary Concern**	**Secondary Concern**
Self-driving vehicles	Being more efficient than manual cars (performance)	Pricing (socio-cultural)
Human-driven vehicles	Changing rules of the road(regulations)	Comfortability/acceptance (socio-cultural)
Pedestrians	Safety (socio-cultural)	Reduced Accessibility (Socio-cultural/performance)
Insurance Companies	Liability (Regulatory)	
Provincial Government	Infrastructure (regulatory/performance)	Environmental Incentive (Environmental/socio-cultural)
Driving Companies (eg. Uber)	Loss of Business/change in business (Socio-cultural)	New/change in laws (Regulatory)
Student Drivers	Licensing (Regulatory)	Price (Socio-cultural)
Families	Safety (Socio-cultural)	Economics (Socio-cultural)

Peruse the data found here: [Public Safety Data Portal]

Which stakeholder would seem to be inordinately affected by Safety/Regulatory concerns? Does this agree with previous answer? Write 2-3 sentences how you think self-driving vehicles may alter these statistics. What are your instincts?

Pedestrians seem to be the most inordinately affected by safety / regulatory concerns. Self-driving vehicles may lower these statistics in various ways. Using self-driving vehicles would essentially factor out human error. The system would be able to detect pedestrians crossing the street and would react to that more accurately than a human-driven car. In the panic-filled situation of trying to avoid a collision, a self-driving car would calculate the best path to avert the incident faster than a human. We believe that if the roadway is accurately mapped, self-driving vehicles have the potential to drastically lower fatal collisions involving pedestrians.

Regarding current **highway designs** have each of your group members independently come up with:

- Two things they like.
- Two things that frustrate them.
- One thing that they would change is they could (this could be about drivers as well)

Do not share your opinions until each group member has come up with their answers. Once complete, as a group share your answers and engage in a discussion. In the box below answer the following questions:

- What positive aspects did you agree on?
- What negative aspects did you agree on?
- What (if any) aspects did you disagree on?
- Were any of the proposed changes controversial within your group? Why?

Like:

Freedom/independence
Connections/inter-city travel
Good speed limits
Wide lanes
Straight driving (no turns)

Dislike:

Bad drivers
Lanes not maintained
Construction
School buses/public transport
Lane splits
Infrequent exits

Disagreement:

- Windey rural highways
- HOV lanes

Changes:

- Less winding roads
- Better maintenance
- Better weather control

- Tolls

We did not disagree on any of the potential changes.

For the things you would change about the highway, identify if these changes would be possible under the following conditions: all vehicles are self-driven, some vehicles are self-driven, no vehicles are self-driven.

	all	some	none
- Less winding roads	Yes	Yes	Yes
- Better maintenance	Yes	Yes	Yes
- Better weather control	Yes	Somewhat	No
- Tolls	Yes	Yes	No

Regarding current **intersection designs** have each of your group members independently come up with:

- Two things they like.
- Two things that frustrate them.
- One thing that they would change is they could (this could be about drivers as well)

Do not share your opinions until each group member has come up with their answers. Once complete, as a group share your answers and engage in a discussion. In the box below answer the following questions:

- What positive aspects did you agree on?
- What negative aspects did you agree on?
- What (if any) aspects did you disagree on?
- Were any of the proposed changes controversial within your group? Why?

Like:

- Roundabouts
- Yield/merge right turns

Dislike:

- 2-step pedestrian crossing
- Unnecessary 4-way stop
- Long Wait times
- Mismatched traffic light timing
- Priority light
- Short-timed yellow lights
- Street parking
- Faded street markings

Disagreement:

- Speed bumps
- One way roads

Changes:

- More roundabouts
- Longer yellow lights
- Less all way stops
- More Yield/merge right turns

None of the changes were controversial.

For the things you would change about the intersection, identify if these changes would be possible under the following conditions: all vehicles are self-driven, some vehicles are self-driven, no vehicles are self-driven.

	all	some	none
- More roundabouts	Yes (would be obsolete in this scenario)	Yes	Yes
- Longer yellow lights	Yes (would be obsolete in this scenario)	Yes	Yes
- Less all way stops	Yes	No	No
- More Yield/merge right turns	Yes	Yes	Yes

If you were driving a traditional vehicle on a road which was designed to also account for self-driving vehicles, how might you treat a self-driven vehicle differently? Would you? Consider the cases where you perfectly trust the self-driving technology, vs not trusting it at all. Put your group's answers in the box below. It's not required to answer the question, but you may be interested in reading this:

[Human Drivers and Autonomous Cars Mix Like Oil And Water]

A self-driving vehicle is attempting to emulate a perfect human driver, and so it should not be treated any differently on the road. If you perfectly trust the self-driving technology, you will treat it like any car on the road. Some people, however, may realize that these self-driving cars prioritize safety and may try to use it to their advantage in a way such as cutting off a self-driving car to make a turn sooner. On the other hand, a person who does not trust a self-driving vehicle at all would give it a lot of distance and space, similar to what you would give a beginner driver. This case is actually not ideal for a self-driving vehicle, as typically these vehicles try to use machine learning to find out how to best drive on roadways.

What would be true about a poorly designed intersection and/or stretch of highway. Or in other words, what would be true of a perfect highway/intersection? Could it be there are two distinct designs, but it cannot be said one is better than another? If so, what would have to be true in this scenario?

A poorly designed intersection is a 4 way stop (inefficient fuel economy, inefficient use of time)

A perfect intersection would have no stop signs or stop lights, minimal stopping and therefore less waiting time, and prioritize pedestrians' safety

A poorly designed large highways with many splits and confusing exits, or one with only one lane

A perfect highway would have no congestion, with 4 lanes with an express lane

There can be two distinct designs, they can have the same performance and be optimal but can be compared without necessarily declaring a certain better option. This is because everyone will have their own preferences despite the two designs being the same performance wise.

Read the article found here: John and Main tops the list of Hamilton's most dangerous intersections for pedestrians

Does their definition of "worst" match up with yours? Is it possible to create an intersection with zero collisions? If so, what would it look like?

- The Hamilton intersection has many pedestrian collisions and has poorly integrated bike lanes that have caused many crashes
- This is different from our definition of a worst intersection, which focuses on the performance aspect rather than the safety aspect of the intersection.
- Yes, you could create the "perfect" intersection, but not in all aspects of the PERSEID method. There would have to be a trade-off. For example, you could have bridges for pedestrians over all the intersection to make sure there are no pedestrian collisions, but this would be extremely expensive (bad socio-economic).
- Therefore the "perfect" intersection depends on the location, and what parts of the PERSEID method you want to focus on and optimize.

As a group, discuss which project option interests you more: the highway or the intersection. For the remainder of the course/project, you will focus on **only one of the two options**. In the box below declare which project option you wish to proceed with and give a justification as to why your group chose one over the other.

Our group chose to proceed with the intersection project option as there are more variables to discuss and modify. We also feel that there are more flaws in the current intersection system that would be interesting to fix.

Week 4: Synchronous Design Studio

Self-Driving Infrastructure Project

System Definition Continued

Overview and Goals

- Identify formal metrics of the system. Explore how an underlying metric such as travel time can be used in several ways.
- Consider parameters/input and outputs to the system.
- Think about what quality attributes are important for traffic systems.
- Formally describe your system.
- Begin thinking about simplistic ways to model traffic.

Take some time to discuss the asynchronous activity you completed this week. Have each group member share an unintended consequence which they identified. Document these consequences below:

Performance:

- People won't own a car
- Subscription to car service
- Road maintenance, cost increase
-

Socio-cultural:

- Disruption of car company business model
- Budget may become unaffordable to own a car
- Loss of jobs, drivers, manufacturers
- Decrease in use of public transit

Environmental:

- Electronic waste
- Production of battery

Regulatory:

- Laws for car accidents (who's accountable?)
- Who pays for the infrastructure
-

One of the more obvious metrics for your project would be *travel time.* This could refer to the time to pass through an intersection or drive down a stretch of highway. What other metrics would be of interest to you? Think of these as the outputs of the system. What information would you or others be interested in? For each metric assign a single PERSIED layer which you believe best corresponds.

- Fuel economy (Performance)
  - How many litres/watts used per kilometer?
- Accident rate (Socio-cultural)
  - How many accidents per kilometer per year?
- C02 emissions (Environmental)
  - Emissions for production of all components of vehicle and driving, in kg C02
- Intersection throughput (Performance)
  - How many cars get through the intersection per day?
- Congestion (performance)
  - Number of cars meter squared of road
- Number of traffic tickets issued per year (regulatory)
  - Red lights, speeding, etc.

Consider three drivers, A, B, and C, which test out three different traffic designs. The table below summarizes the travels times of the three drivers across the three designs. Time units have been left off on purpose.

	A	B	C
Design 1	6	4	2
Design 2	1	10	20
Design 3	5	5	5

Which of the three designs has the best performance? Why? Can you think of a way to measure things such that each of the designs would be considered the *best*? If you were a driver, which design would you rather have implemented? Why?

Design 1 was deemed to have the best performance because it has the lowest average time, with 4, compared to the other designs. If we based the measurement on consistency, then design 3 would have the best performance. For design 2 to have the best performance it would have to be based on having the lowest time individually.

As a group we think if we were a driver, we would rather have design 3 implemented as it the most fair and consistent across different drivers.

For the above data, if you attached different time units to these numbers, does it change your perception of this at all? As an extreme example, a human likely would not care if it took 20 or 10 nano seconds to pass through and intersection. Discuss below:

Changing the units of time does change the perception of the chart. For example, the differences between the travel times are not very important by the second or minutes, but by the hour it becomes a bit more unfair across varieties of drivers.

Thus if the travel time was in seconds or minutes, our answer would not change, but if it was in hours we would definitely choose design 3.

An aspect of traffic which is hard to nail down is *fairness*. Take a few minutes to individually define what you think it means to be fair from a traffic perspective. Be as formal as possible (assign numbers/formulas to your definition). What scenario do you consider fairer than another? Documents your group members definitions of fairness below:

Time to get to where you want to be vs the average = time spent traveling / average time to get to the destination
Fairness in terms of traffic would depend on a few factors such as consistency, priority, average time spent waiting. With consistency, everyone waiting and taking the same (within a 10% range) time to go through an intersection is most fair. However, when priority is considered, it's not fair to stop a four-lane road with lots of traffic for a small residential road. True fairness is a balance between the two with consistency.
When considering traffic, fairness is when everyone's travel times are within 5% of the average travel time (if measuring by the same point A to point B).
Fairness from a traffic perspective is not having to stop any longer than other vehicles.

Once complete, compare definitions of fairness. Are there any disagreements? Of the three above scenarios which are fair and which are unfair? Is fairness in contention with performance? Answer below.

- Some group members compared the individual to the average travel time, while others compared the average overall to see if the distribution is within a certain value - Some group members focused on the amount of time to get to where they want, while others compared it to the time spent stopped

- If your definition is focused on making every individual fall within a certain "fairness" value, then the performance will be hindered. Whereas fairness is measured by an average across all drivers, then fairness goes hand in hand with performance.

In system engineering "quality attributes" are used to evaluate aspects of the system which are difficult to measure. For example, we have all had experience with products which are easier/more intuitive to use than others (think about websites and phone apps), but how would an engineer measure *useability*.

Take a look at the article here: List of system quality attributes

- Which attributes do you think apply to this project? Choose 5, what would those attributes explicitly be referring to in the context of vehicular traffic?

- Safety
    - How much less fatal are the crashes (eg. Minimizes head on collisions)
- Dependability
    - How well can we rely on the system to get drivers across the road safely?
    - How well does the system work in different weather conditions?
- Composability
    - How well do the traffic management systems connect and work with the data provided by the
- interoperability

- How well this can be adapted to other systems such as current traffic management systems
- How well this system works for users other than drivers (eg. Bikers, pedestrians, etc.)

- serviceability
  - How easy would it be to fix the system?
  - How long would it take to fix?
  - How expensive would it be to fix?

Up to now you have been looking at the *outputs* of the system, but what are the inputs? What describes your design? What are the parameters? The remainder of this design activity deal with these questions.

Before you can begin to simulate and assess particular designs, you need to create a formal model. Creating this model will be ongoing over the next few weeks but we need to begin now. Start by thinking about a very simplistic version of your final vision. For example, if you are designing an intersection, constrain the model to only having self driving cars arrive to a four-way stop. Or for a highway, limit it to two lanes and again limit it to self-driving cars only. List some assumptions which will aid you in modelling this simplistic system. For example, an assumption could be:

- All self driving cars at the intersection are fully aware of all other cars
- All self driving cars will have either a target speed of 110, or 130.
- Cars will arrive to the system exactly every 30s.

List some assumptions (you can relax/remove them later).

- All cars considered are self-driving
- Only cars, no bikes, trucks, pedestrians, etc.
- All self-driving cars at the intersection are fully aware of all other cars
- All cars stop and accelerate at the same rate
- The roads are well maintained and equipped with any necessary sensors

- The roads are straight coming into the intersection
- Weather does not impact performance of system
- There are no visual obstructions
- The roads are smooth (no potholes)
- The cars can read the traffic lights and traffic signs
- The cars can detect lanes

Discuss how the overall system will behave and how you might simulate that in code. You do not have to actually write the simulation! Hint: It will help to make things discrete. For example, a two-lane highway could be represented by a 2 by *n* array (each row representing a lane), where each cell of the array represents *x* feet of highway. That cell may be occupied by a car or be free. Discuss your representation below. Consider the following:

- How/when will vehicles arrive/depart from your simulation?
- Will this differ between self-driven/human driven vehicles?
- What happens as vehicles progress through the simulation?
- What information is required to describe a "snapshot" of the system?

If struggling to answer this question, begin by discussing how a self-driven vehicle will behave differently from a human-driven vehicle (speed, follow distance, reaction time, etc.)

- How/when will vehicles arrive/depart from your simulation?
    - Each vehicle is an instance of an object
    - Each vehicle runs a function to check the conditions if it can go (is the light green, are there any cars in front of it, etc.)
- Will this differ between self-driven/human driven vehicles?
    - All cars are self-driving (assumed for simplification) so this does not matter in our simulation
    - There will be no difference

- What happens as vehicles progress through the simulation?
  - There is while loop that checks whether a certain value is met
  - This value would be updated at certain instances (eg. Passing a light)
- What information is required to describe a "snapshot" of the system?
  - Variables of each vehicle object will describe speed, location etc.

From the previous two questions, review your assumptions and simulation ideas, and see which ones can be considered (or massaged into) input parameters for your model. For example, a parameter may be: *number of lanes, proportion of self-driven vehicles*, etc. In general, the idea will be you can change the numerical values of these inputs later on to see how the outputs of your design are affected.

Parameter	Description (include measurement units and/or example values
Number of lanes	The number of lanes relative to an intersection (#lanes in/out of the intersection)
Max speed	The maximum speed a vehicle can drive on the road (km/h)
Relative location to intersection	How far a vehicle is from an intersection (meters)
Number of human driven vehicles	How many cars are human driven in an intersection
Protected left turn	Does the intersection have a protected right turn or not (True/false)
Does the Intersection	Will the road be wide/strong/be free enough to support large, commercial vehicles (True/false)

support large vehicles (eg. Trucks)	

Week 5: Self-Driving Infrastructure Activity 5

Overview and Goals

- Discuss and review the simulation code
- Begin brainstorming preliminary feasible designs
- Informally identify potential strength and weaknesses of those designs
- As a group, elect three of your designs to move forward with over the next few weeks.

For the first 20-30 minutes of the design studio, discuss the simulation code provided to you. Make sure all your group members are on the same page and understand how to run the simulation. Try running a few simulations in the studio. Document your discussion below via the points below:

1. What experiments would you be interested in running? In other words, what parameter ranges would you be interested in testing?
2. Was there anything in the code some of your group members did not understand? If so, as a group were you able to resolve this?
3. What changes would you like to make to the code? That is, what factors are missing from the simulation that you would be interested in adding? This will tie into your design choices later in this design studio.

1. Experiments:

   - If two cars come from the same direction, how long would it take for them to both clear the intersection

- If two cars from two opposite direction reach the intersection at the same time, how long would it take for them to clear the intersection
- If all cars from each direction arrive at the exact same time, which car would go first? (Infinite counter-clockwise loop)
- Try random stop and clear times to see how that would affect the average clear times
- Try to have multiple cars “clearing” the intersection at one time

2. How the clear time of the cars was generated, we looked over the code together and found out it was a constant value in the code.

- How the direction of the approaching car is generated (based on a randomly generated number)
- How events were generated and stored. Analyzed the code and found that they are stored in an array called queue.
- How individual vehicles are represented. Found that they are represented as instance of class Car

- How the simulations are run (by storing all events in an event queue, then printing all these events in a for loop)

3. Add the type/class of each vehicle (SUVs, Sedans, trucks, etc.)

- Different start and arrival times depending on the vehicle
- Add multiple lanes to the intersection
- A way to distinguish between motorists and bicyclists
- Some way to simulate pedestrians crossing
- Two class for self-driving and human driven to differentiate
- Assigning a random speed value (within a range)
- Assigning a velocity and acceleration for each vehicle

How does uncertainty/non-determinism/randomness affect technical performance? As an example, consider a system which behaves similar to a first-in-first-out queue, where drivers have to wait for drivers ahead of them to pass through the system before they can. Consider the following two versions of this system.

1. Drivers arrives precisely every 30 seconds and it takes exactly 25 seconds for a driver to clear through the system (everything is deterministic here)
2. Drivers arrives precisely every 30 seconds and drivers now take either 10 seconds or 40 seconds (each occur with 50% probability) to clear the system

How do you think the performance of the two systems differ? In the simulation code you were provided, identify some deterministic and non-deterministic values. Which (if any) deterministic elements do you think would be interesting to change to non-deterministic? What do you think would be the overall impact to technical performance?

The first system would be optimal because by the time the second car arrives, the first car will have already cleared the intersection. Although this first model is unrealistic in showing the function of a real intersection. In comparison, depending on the random values that we receive from the second, the performance will either be on par (if the clear time is lower than 30 seconds) or worse than the first scenario.

Deterministic:

- Stop time
- Clear time
- Mean arrival time
- Number of vehicles in intersection
- Number of lanes

Non-deterministic:

- Direction of the vehicle

- Actual arrival time
- Wait time

Change from deterministic to non-deterministic:

- Number of vehicles in intersection
- Clear time of each vehicle (some vehicles accelerate faster)
- Stop time (heavier vehicles stop slower)

Impact to technical performance:

- If the number of vehicles in the intersection becomes non-deterministic, then this would influence performance positively. If two cars are arriving from opposite directions (e.g. North and South), then they may clear the intersection at the same time and improve performance. If they arrive from perpendicular directions, then they would still have to wait.
- If clear times and stop times become non-deterministic, the impact on our design would depend on the random values we obtain. In general, a deterministic system would have more predictable and better performance, because we would know exactly how long each car takes to arrive and account, but this would not be very realistic.

As a group create a set of non-trivial designs for your system. Note, here, a design could be the structure/layout of the road, or the *driving policy* implemented on that road (or some combination thereof). Aim to have 5-6 designs total. These designs should be non-trivial and offer a reasonable level of complexity. For example, a four way stop with a simple round-robin policy would not suffice. At this point do not get bogged down with potential issue with the designs (weaknesses/flaws), that will be handled in the next step.

For each of your designs you must identify how the design handles both self-driven and human-driven vehicles.

1. 2 lane roundabouts
2. Emulating a timed traffic light, where parallel directions are allowed to cross, and the time of each light is determined by the number of cars in each lane
3. Stop system but with yield right turn lanes, where drivers that are turning right do not have to stop at the intersection.
4. Stop system but using the self-driving system to have cars stop only when necessary. For example, cars from parallel directions can cross at the same time as long as it can be determined they will not crash.
5. Having one lane go over the other lane like a highway bridge

Have each group member individually rank your previous designs. There are many ways to evaluate a design, and no design is perfect, but the ranking should have a rational explanation. Compare ranks as a group. Do they agree? Disagree? For each of your designs identify at least one strength and one weakness from a performance standpoint only. Then, again from a performance standpoint alone, create a ranking of your designs that you as a group agree upon.

Housam's Ranking:

1. Self-driving stop system: this is by far the best option as it will have the best performance as wait time of all vehicles is minimized.

2. Traffic light with yield right turns and protected left turns: this is by far the best option that accommodates both self-driving cars and human driven cars. The only disadvantage of this design is that it will not have the same level of performance as all self-driven.
3. Traffic light without any extra traffic management systems: Same performance as previous option but does not have extra options to reduce wait times like yield right
4. 2 lane roundabout: allows for decent amount of performance but if there are many cars in the lane the wait time will be very high.
5. Bridge: Will provide the best performance but will be very expensive to build and we will be limited in the areas where it can be deployed.

Allison's Ranking:

1. Stop system using self-driving cars (4) - Eliminating the need to stop every time and allowing the cars to be closer together/having multiple cars clearing the intersection regardless of direction, which is possible with focusing on self-driving cars
2. Traffic light with light changing based on cars waiting (2) - This design would allow for both self-driving and human-driven cars, and would focus on prioritising those who have waited longest. It would also eliminate the need for all cars to stop at the intersection, improving average wait time.
3. Two-lane roundabout (1) - This allows for good throughput of both self-driving and human-driven vehicles, reduces wait time by not having to stop at all, still on average it could be slower than above traffic light as cars need to slow down regardless of opposing traffic.
4. Stop system with yield right (3) - This would increase throughput from a basic stop system and allow for multi-lane intersections to have multiple cars clearing the intersection at once. However, I feel like it is already very similar to what infrastructure is already used, and although the use of self-driving cars will allow for some decrease in wait time, I don't believe there will be a significant enough change for people to feel the price of a self-driving car is worth it.

5. Bridged intersection (5) - This design is not realistic and not only limits the direction of travel but adds complications for pedestrians and is not very cyclist-friendly, very expensive and not feasible for numerous intersections.

Mohamed's Ranking:

1. Stop system with self driving (Design 4): Would have decent performance, would make it so waiting times may even be lower than the current simulation

2. Emulating traffic lights (Design 2): Transitioning to this design would be easiest from our current intersections, where traffic lights turn green faster on larger roads that have more vehicles. This design would be able to more accurately decide when to turn the lights green and red based on how many vehicles are waiting

3. Stop system with yield right turns (Design 3): This would have decent performance in a multiple lane intersection. This is because there is less risk of collision with self-driving vehicles, and so as cars are proceeding straight through the intersection, cars turning right onto the same road are able to stay in their lane and make the turn without colliding

4. 2 lane roundabout (Design 1): It is hard to imagine a roundabout that would be more efficient than the options I put above this one, especially under heavy traffic

5. Bridge (Design 5): While it could be effective for going straight through an intersection, it eliminates right or left-hand turns and is more costly.

Kelly's Ranking:

1. Design 1 - 2 lane roundabouts: this design allows for compatibility between self-driving and human driven vehicles, and I personally think it will be the best option for when both cars must operate on roadways together. This design allows human-driven vehicles to behave as similarly as they can to self-driving cars in that they will not have to stop at all intersections. A drawback would be that if there are too many cars the wait time may be high, so a functional capacity would have to be experimentally found.

2. Design 4 - Self-driving stop/yield sign system: benefits of this design is that it will keep the flow of traffic moving since self-driving cars will be able to clear intersections where there is no one which will reduce congestion. Drawbacks of this design is that with the uncertainty in number of self-driven and human-driven cars, it is hard to predict how much time this design would save in comparison to the others.
3. Design 3- stop system with yield right turn lanes: This is combining the 2-lane roundabouts idea with a traffic light and has advantages with human-driven vehicles since there is much familiarity with these intersections. While they do not always keep traffic flowing, they are more feasible and time efficient than classic traffic light designs. Drawbacks include not being able to utilize self-driving vehicles to their full potential.
4. Design 2 - Timed traffic light: may have congestion on busier roads during commute hours but
5. Design 5- bridge design. While this would be a good design in terms of travel times, it is not realistic and is too expensive

Comparison Agreement and Disagreement:

Most group members agreed that the stop system that utilized self driving car capabilities was one of the best options because of its vastly superior performance and safety. Many group members placed the traffic light system near the middle of their lists because of its acceptable performance and safety compared to the other designs, however, some group members believed that the traffic light system was not a good design because it was too similar to current intersection designs and wouldn’t provide a vast enough change in safety or performance to pursue.

Finally, there was disagreement regarding the roundabout. Some group members thought it brough a great idea to implement a roundabout because it would be one of the safest designs because head on collisions are minimized, while other group members placed roundabouts near the bottom of their lists due to their lackluster performance when handling a large number of cars as well as the amount of space they take up.

Group Ranking:

1. Design 4 (Self-driving stop/yield sign system)
2. Design 3 (stop system with yield right turn lanes)
3. Design 1 (two laned roundabouts)
4. Design 2 (Emulating traffic lights)
5. Design 5 (Bridge lane going above the intersecting lane)

From your designs, as a group choose 3 to move forward with. Explain why you chose these designs. Do not stress out too much, if you change your mind or come up with a different idea over the next few weeks you can always *switch* things up.

1. Design 4 (Self-driving stop/yield sign system)
2. Design 3 (stop system with yield right turn lanes)
3. Design 1 (two laned roundabouts)

   We chose these designs because we believe they will improve performance the most while also considering self-driving car capabilities and the transition for human-driven vehicles. Specifically, we think that congestion can be reduced/managed well and in a safe manner with these traffic designs.

Week 6: Self-Driving Infrastructure Activity 6

Overview and Goals

- Discuss answers and results from the asynchronous activity
- Gain a deeper understanding of statistical wealth distribution
- Formalize Socio-cultural concerns
- Begin brainstorming/re-evaluating designs from a Socio-cultural viewpoint

Take roughly 15-20 minutes to review and discuss your group's asynchronous activities. Share your answers below:

- We all underestimated the average person's net worth
- We forgot to account for the higher end of the population who skew the average up
- We all based net worth on ownership of property and liabilities
- We all thought being Canadian makes you more likely to have a greater net worth, since Canada is a developed country while most of the population lives in developing countries with lower salaries, and because the $CAD has a higher value than other currencies.
- We all thought people over 35 were more likely to have a higher net worth because they have had a longer chance to accumulate wealth
- We also thought ownership of a car would also increase net worth, despite cars being an expensive asset due to insurance and gas, but people who can afford a car are more likely to have a higher net worth.
- We discussed how owning a home is more likely to make you have a higher net worth
- Where the person lives (city vs country) affects net worth, average person living in the city would have a higher net worth than someone living in the country
- Depending on what race a person is, they are more likely to have a higher net worth
- Having a post-secondary school education increases likelihood of having a higher net worth
- Males are more likely to have a higher net worth because of barriers to entry into higher paying jobs
- Age of retirement: able to retire early probably has a higher net worth vs someone who retires later
- Being married makes one more likely to have a higher net worth than someone who is not
- Having kids makes someone more likely to have a lower net worth than someone without kids
- Having student loans, directly lowers an individual's net worth
-

Consider the following expression:

$$f(k) = E[\text{Networth}(X) \mid k < \text{Networth}(X)] - k$$

Spend some time unpacking this expression. As a group determine the following and write your answers below:

1. In plain English, what does f(k) represent?
2. What does your intuition tell you about f(k), is it increasing in k, decreasing, a combination, etc.? Justify your claim. To help you out, consider some concrete numbers for k: 1,000 vs 1,000,000,000
3. How does f(k) compare to E[Networth(X)]? That is, <, >, =, depends on k, etc.

1. f(k) represents the amount of deviation of new worth for people who make more than k
2. That as you increase k, f(k) would also increase as the spread of net worth is much larger among the very wealthy. In addition we are decreasing the number of data points, causing more deviation.
3. The comparison of f(k) and E[Networth(X)] will depend on the input of k. For lower k values, E[Networth(X)] is more likely to be higher, while when k I large, f(k) is likley to be larger.

Not Required: If you are interested in learning more of the mathematics of this, research heavy-tailed distributions, specifically, the Pareto distribution. Note, the Pareto distribution accurately models real-world wealth distribution (and much more). You can find more details here.

Consider the following expression. How would they compare to each other? Based off your past observations on the distribution of wealth, what can you conclude? Answer in the space below. Furthermore, relate these expressions back to stakeholders within your project.

1. E[Networth(X) | Owns self-driving vehicle]
2. E[Networth(X) | Does not own a self-driving vehicle but still owns a vehicle]
3. E[Networth(X)] | Does not own a vehicle]

- E[Networth(X) | Owns self-driving vehicle] > E[Networth(X) | Does not own a self-driving vehicle but still owns a vehicle]

Self driving cars are on average more expensive than the non self driving cars, thus the people who own self driving cars are more likely to have a higher net worth.

- E[Networth(X) | Owns self-driving vehicle] > E[Networth(X)] | Does not own a vehicle]

People who own self driving vehicles are more likely to have a higher net worth because self driving cars are an expensive asset to purchase

- E[Networth(X) | Does not own a self-driving vehicle but still owns a vehicle] > E[Networth(X)] | Does not own a vehicle]

People who own a vehicle are more likely to have a higher net worth because vehicles are an expensive asset.

We can conclude that owning a self driving makes you more likely to have a higher net worth than if you have a non-self driving vehicle, and having vehicle means you are more likely to have higher net worth than someone who does not have a vehicle. (by transitivity, people who own a self driving vehicle have a higher net worth than someone who does not own a vehicle.)

As a group review your designs from last week – the ones you initially brainstormed with technical performance in mind. This time however, think about each design from a socio-cultural viewpoint. To help you get started, in your past designs, how does the performance of a self-driving car differ from a human driven vehicle. Which groups are you rewarding? Or, which groups are you punishing? For each design other a well thought out critique, and try to rank them from a Socio-Cultural viewpoint only.

Self-driving stop/yield system:

- Individuals who can afford self-driving cars will have a lower time for travel
- Individuals who can afford self-driving cars are likely to be safer
- Pedestrians (people who do not own vehicles) will likely be safer in this system since we prioritize safety of pedestrians in our designs
- Human-driven will act similar to a regular traffic light, giving some familiarity

Complex Stop System:

- Does not favour self-driving vehicles over human driven since a drawback of this design was not being able to utilize self-driving to their full capabilities
- Very similar to current intersection designs, less adjustments needed from people

- Because they are so similar to current designs there’s no added safety for pedestrians and cyclists, although accidents with them is rare it is often fatal
Two lane roundabout: - Favours self-driven only because human driven can have drivers who have never encountered a roundabout before and may be unsure/confused - Harder to cross for cyclists - An obstacle for pedestrians, there’s no straight cross and will also rely on two cars stopping for them to cross - Reduction of fatal crashes because it eliminates head-on and T-bone crashes
Ranking: 1. Complex Stop System :The most “fair” design would be the complex stop system, as it does not favour either self driving vehicles or human driven vehicles, and it is easy for pedestrians to use. And it will also be most accepted by people as it is very similar to current designs. 2. Self-driving stop/yield system: People will be less accepting of this than a traditional “stop system” that they are used to. People will have a hard time trusting self driving cars to drive in a safe manner with no one controlling them. 3. Two lane roundabouts: This is the least fair design since it may create more obstacles for pedestrians and cyclists. We also think there are more people who resist changes to roundabouts vs implementing self-driving car features.

Discuss a few more design you may want to consider if you were only trying to address Socio-cultural concerns. Are these designs reasonable?

- Pedestrian bridge over the intersection, as this would remove the safety concerns for them being hit and the performance of having to wait for cars to stop but again as discussed this is not often utilized and makes it much harder for pedestrians to cross, is not easily deployable in all locations, is expensive, and is not aesthetically pleasing in general
- Stop lights triggered by pedestrians waiting to cross at roundabouts
- Bridge: One lane going over the other lane with merge exits, as this would eliminate the need for any self driving capability and make it fair for both kinds of vehicles, but this would be very expensive and only have limited deploy ability. This would also be very complicated.
- A pedestrian only period for the intersection (eg. Tokyo): this would be the safest and simplest solution to pedestrian safety, however this would severely hinder performance and would only be viable in densely populated urban areas.

Sometimes Socio-cultural factors can be regarded as informal, or "hand-wavy". Can you take a more formal approach to these factors? For example, can you come up with a hard mathematical constraint which would account for at least some socio-cultural concerns?

Hint: You can consider the expected response time of a driver in your design. We could denote this by

$$E[Time(D)]$$

Where D is a driver in your model. Now you can condition on this expectation like you did with net worth and wealth such as:

- E[Time(D) | D is a self-driven vehicle]
- E[Time(D) | D is a human-driven vehicle]

What inequalities/equalities might you want to be true in your design? Explain and justify your answers.

- E[safety(D) | average income of the area]: areas with a lower income are more likely to have pedestrians and bikes, thus we would have to consider this in our design. This would also increase average amount of time to cross
- E[Location(a) | A is area surrounding the intersection] : example a neighborhood, a school zone, a major highway, downtown. Which will affect the number of cars that go through it, the amount of pedestrians and cyclists.
- E[Time(D) | average cost of car in the area]: more expensive cars tend to be larger suvs, so less cars would be able to make it through thus it would take more time to cross

Week 7: Self-Driving Infrastructure Activity 7

Overview and Goals

- Discuss answers from the asynchronous activity, alongside other factors regarding safety with self-driven vehicles

- Brainstorm/re-evaluate designs from a Regulatory/safety viewpoint

- Review your model/simulation ideas to incorporate crashes

In the asynchronous activity we asked how many deaths on our roads is too many. As a group discuss some of the thoughts and comments you had regarding this concept. To help you along with this discussion, as well as the rest of the activities for this week consider the following two words: control and liability. Document your discussion below.

The purpose of the infrastructure is to provide safer and more efficient intersections, and so there should be a lower amount of fatal crashes than a standard intersection. The intersection design should lower the probability of an accident occurring, and therefore lower the number of fatalities that occur. The total death should not be any higher than the Canadian 2020 amount below, and if anything, should drastically reduce the number because it removes the factor of impaired driving.

Transport Canada 2020 statistics:

Total fatalities: 1745, Fatal crashes: 1591, Serious Injuries: 7868

One of the group members had the idea that the number of road deaths should not be higher than the highest recorded road deaths over the past 10 years. After discussion with the group, other group members brought up the valid point that we want our design to improve over time, rather than staying the same. At the same time, looking at road death statistics we see that the general trend is that they are decreasing over time and we want to continue that trend, and preferably increase the rate at which they are decreasing. Thus we want our design to have a lower number of deaths than last year.

Let's try a thought experiment. What if instead of people getting in fatal crashes the following happened. Whenever a fatal crash would occur, some sort of divine intervention takes place and the person that would have died is saved. However, the cost of this divine intervention is at the same time someone is randomly selected from the global populace and killed (let's assume humanely). As a group discuss this situation. In terms of the number of deaths, is it equivalent? Is it fair? Again, return to the ideas of control and liability. Document your discussion below.

In this situation the number of deaths would numerically be equivalent however, we agree that this would not be fair or morally equivalent. With respect to control and liability, the driver liable for the crash would cause a random person to lose their life so holding people accountable for poor driving choices would be tougher to do.

The person who goes out to drive, the driver is taking the risk (whether they know it or not) that they may get in a crash while driving the car. Whereas the person who is randomly killed did not take this risk and thus did not have control over their outcome.

In terms of control and liability, how do self-driving vehicles change things. To help in your discussion consider the three cases below (if you want to consider other cases as well please do so):

1. Fatal crash involving two self-driven vehicles
2. Fatal crash involving a self-driven and human-driven vehicle; the self-driven vehicle is at fault
3. Fatal crash involving a self-driven and human-driven vehicle; the human-driven vehicle is at fault

How does lack of control change our perceptive on driving? Who do you think is liable in these cases? There is no clear/perfect answer to these questions. Document your thoughts below:

1. The liability depends on the conditions. No driver has direct control, as in ability to change the operation of the vehicle, of their vehicle. In terms of liability, it depends on the nature of the accident. For example, if it is weather related and a driver didn't clean off the sensors then that driver is at fault. However, if it's due to the software of the self-driving, the liability shifts away from the two drivers involved in the accident. The lack of control of either person creates a more nuanced situation and moral dilemma.

2. The driver of the self driving vehicle was not in control, thus he is not at fault. The manufacturer of the self driven vehicle is at fault because the designers should account for every possible situation the car may be in. Thus unless there were extenuating circumstances where the road condition was unacceptable (weather, bad road) then the self driving manufacturer is at fault.

3. The liability and control are remarkably like a human-driven vehicle car crash currently. Since the driver of a human-driven vehicles still has control over their vehicle, they would still be at fault and therefore liable.

What about pedestrians? In a self-driven vehicle that is owned by its *passenger* what should happen when the technology has to make a choice between hitting two individuals which are jay-walking, or crash into tree to avoid them? What do you think should happen? What if one of the jay-walkers is a child? What if there's a baby in the back-seat of the car? Who is even responsible for making these decisions? Discuss this as well as other (potentially uncomfortable) scenarios below.

As a group spend a few minutes Judging the scenarios found here: Moral Machine

This question is very complicated to answer, as there are many factors to take into account. A simple answer would be to say pick the answer that saves the most lives, but this is an oversimplification, as if the number of lives saved is the same for both options, how do you choose? Also, what if the jaywalkers have a baby, which still potentially has many years to live, while the car has an elderly driver who is near death, killing the baby will cause more "years of life" to be lost than the equivalent elderly driver. This comes down to placing a value to each human life of the equation, which could include genetic fitness, occupation, background, health issues, etc. The other factors that can impact the decision is will people drive self-driven cars if they always swerve to avoid jaywalkers and therefore putting their safety below others. In the end we concluded that any human life lost is not good and needs to be avoided at all costs but would pick the option that results in the lowest number of deaths and if equal which results in the least amount of years lost.

The responsibility of the results falls onto the company that designs the cars and more specifically the people that designed the software that makes the decision for the self-driving car. This can also shift to the government with the development of new regulations regarding self-driving cars.

Spend five minutes individually answering this question. If you were the supreme (benevolent) dictator of Canada where your word is law, which laws would you impose/enact to govern infrastructure with self-driven vehicles (with safety in mind).

a guide to research on regulatory requirements is provided to you [ENG 2PX3 Guide to Standards and Regulations] under [5-Design Studio → Week 7]

After 5-10 minutes, share your answers. Document them below.

- The first law I would enact would be self driving vehicles must be tested extensively before they are allowed to drive on the roads. Self driving vehicles must have an accident rate of close to 0%.
- Any self driving car that causes an accident, the liability will fall soley on the manufacturer of the vehicles
- There will be laws in place to ensure that the driver of a self-driving vehicle must ensure the safety of their vehicle before driving. For example, make sure the tires are not flat, the headlights work, all the sensors are clear. If this is not the case, the driver will be deemed responsible for the crash.
- The self driving cars must give the driver a warning before driving if the car is not fit for the road (eg. Tires are flat or sensors are obscured). This will not prevent the car from driving, but it will allow the driver to know when the car is not functioning properly.
- With safety in mind, the first law I would enact would be a general outline for a crash protocol and a new standard for in-car safety crash features, for instance consider

location before bailing on a dangerous situation since bailing is not an option on a busy road or a mountainy roadway

- With safety in mind self-driving vehicles would have stricter regulations for predicted behavior, since human emotion, mental state, physical state variables are removed from the complexity of driving, making complex situations simpler. Some of these behaviours would be speed, lane changes, red lights, etc. self-driving cars would be held to stricter rules.
- There must be regulated updates as road rules can change due to construction, to changes for safety such as a new crosswalk. Self-driving cars must be aware of the changes and have their data set updated in a timely manner as to not cause issues.
- Self-driving cars will have regulations and be enforced to get more routine maintenance, as the status of the vehicle is more important as it can't be adjusted for like how a human driven car can be corrected for a wobbly wheel but a self-driven can't

As a group critique your other groupmates laws. Try to think about tricky cases where the law could be problematic. How would these laws be enforced? As a group, which laws did you all agree on? Which laws did you ultimately deem a bad idea? Document your discussion and justifications below.

- What if the self-driving car has a malfunction with a sensor halfway through driving, should the car stop working and force the driver to pull over? Will the driver be responsible if a crash occurs after this malfunction.
- Who will pay and be responsible for the testing?
- How can the accident rate enabling cars on the roadways be known without using the vehicles first

- We all agree with the last point where the self-driving car is held to a higher standard in terms of laws, as there is no excuse for self-driving cars to break road rules under ideal weather/road conditions

Re-evaluate your designs/idea from the previous two weeks. Of your designs, which do you argue to be the safest, which is the least safe. Rank them and justify your choices below.

The design that is the safest is

1. Design 4 (Self-driving stop/yield sign system)

This is the safest design since there are many regulations already in place that could still function virtually the same with the addition of self-driving vehicles. This again may not have many performance benefits but based strictly on safety it is the best option.

2. Design 3 (stop system with yield right turn lanes)

This design is a medium since it adds complexity and therefore more responsibility to the car manufacturers and human drivers.

3. Design 1 (two laned roundabouts)

This design adds complexity, it can often create confusion with the yield rather than stop. Additionally, pedestrians will have a hard time crossing as there would need to be multiple crossing locations that are not always visible. Thus, this added complexity will increase the number of crashes, but decrease the fatality of the crashes since there are no head on collisions

Do you notice any direct relationships/interactions with the other PERSIED layers? For example, one of the safest intersections I can imagine is one with all red lights all the time. Or on the other hand, all green lights all the time mean you make really good time clearing the intersection, or crash. What is the compromise here? Discuss this as a group and document it below.

The best performance would allow for cars to never stop but unfortunately this creates more risk for crashes. Performance and regulatory appear to be inversely related for this reason, but at the same time there must be an improvement with the use of autonomous vehicles which would be measured via fatalities. Social-cultural and regulation go closely in hand because for social acceptance safety was one of the largest concerns which is address through the use of strict regulation.

There will always be compromise between the different PERSIED methods, and the self-driving intersection is no exception. Safety will always contend with performance because the increased reaction time of the self-driving car will increase performance but will still have to correspond with the slower reaction times of human drivers. Thus, time to cross intersections will be hindered by human drivers, and any increase in speed may increase the amount of crashes.

This also consider with regulations, which will have to account for all possible crashes and who will be held responsible for them. Finally, the socioeconomic aspect will be another factor to consider as some people may not be able to afford self driving cars.

As it stands now, the base code you were given for your simulations has no possibility of a crash. At the intersection all drivers stop and follow the rules. On the highway all lane changes are safe, and cars slow down accordingly. Revisit your model and simulation code. What things would you need to change to now model/simulate vehicles crashing. How would you account for different types of crashes – fatal vs a fender-bender, for example. As always, discuss and document below.

We would have a function that randomly (some specific value) causes a crash when a vehicle is driving through the intersection. The severity of the crash would also be determined semi-randomly, with speed as well as randomness impacting the fatality of the crash. We can also take into account the type of vehicles and the direction of the crash to determine the outcome of the crash. This would give us a good idea of the behaviour of our system when crashes are included.

Week 8: Self-Driving Infrastructure Activity 8

Overview and Goals

- Discuss answers from the asynchronous activity, alongside other factors regarding safety with self-driven vehicles
- Create some simple mathematical models to quantify fuel efficiency of self-driven vs human-driven vehicles; apply these models to your designs
- Brainstorm/re-evaluate designs from an Environmental viewpoint

In the asynchronous activity you explored the environmental impact of electric vs gasoline vehicles, what conclusions did you come to? Discuss this as a group. What fact/statistics did you find the most interesting/compelling. Are you all in agreement? Document your discussion below

- That electric cars are worse than gas cars in terms of environmental impact in the beginning of their lifespan due to production emissions, however they have zero tailpipe emissions so over their lifetime they have a smaller environmental impact than gas vehicles
- There is around 30-40% more emissions with the production of electric vehicles vs. gasoline, this varies due to different unsustainable mining practices across the world, as well as unethical mining practices
- Gas vehicles (currently) have a smaller environmental impact when being produced
- Electric vehicles are not completely emissions free as the electricity the car uses is generated by power plants
- Depending on the location of the vehicles, the electricity grid could be powered by renewable sources such as wind, or fossil fuels such as coal
- Use of EV in China actually increases the environmental impact of traffic because their electricity grid is powered by coal and fossil fuels at such a large scale
- This has a huge impact on the environmental impact of an EV
- Non-exhaust PM emissions increase for heavy vehicles (tire, brake, road wear) and EV are on average 24% heavier than ICE
- EV reduce direct black carbon emission from vehicles and provide better air quality in near vicinity
- The impact of the energy grid is ultimately more promising than continued production of gas vehicles since it provides opportunity to improve
- The research into recycling and reusing of retired EV batteries has the potential to supply more than half of the cobalt, lithium, and nickel in new batteries

As a group discuss your ideas from the asynchronous activity regarding the environmental impacts of infrastructure. These could be about your specific designs or infrastructure (roads) in general.

Specifically, focus on the complexities that environmental factors introduce when considering the other PERSEID layers. To get you going, consider the points below:

- From the Socio-cultural activity you concluded that individuals without self-driven vehicles are more likely to be marginalized/poor. So, incentivizing self-driven vehicles could be problematic. If you are concerned about environmental factors, does this still hold?

- Over 25.000 crashes occur each year involving ungulates (deer). Many of these result in injuries and some result in fatalities.

  11 Canada Deer Car Accidents Statistics for 2022

  If you only cared about regulatory/safety factors, then we need to eliminate these deer! Should we go shoot them all? I hope not. As an aside, a whitetail deer weighs about 150 pounds, how much do you think a bull moose weighs? Now Google it. Think about where the driver is in relation to that animal when they hit it. In parts of Ontario large fences are put up along the road to stop moose from crossing. Does this have an impact on the moose population? Moose have to get around too.

- From physics we know that the faster something goes the less efficient it is (it we aren't in a perfect vacuum). Wasted fuel means more fuel used means more of an impact on the environment. Therefore, we should make the highway speed limit 60 km/hr.

In addition to the points above discuss with your group some other cases to consider.

1. Yes, we still need to consider less wealthy people when incentivizing electric vehicles, especially when the environment is involved. The fact that electric vehicles are better for the environment is actually a positive for people who are less well off, as this will decrease the amount of pollution in the air in the less wealthy areas where they live. As well with the current interest and research in electric and self-driving vehicles, with

their selling point being that they are better for the environment, their environmental impact will keep decreasing, so it is a positive to encourage a shift to electric self-driving vehicles. With this shift, it will be equally important to ensure there are affordable mass-market options available, as well as not incentivizing the purchase of EV's since this will only reward the rich, there could instead be a government incentive to purchasing an EV when you make below a certain salary.

2. For crashes involving deer, the self-driving capabilities can help reduce the number of crashes involving deer, as these crashes usually happen at night where visibility and reaction time is an issue. Self-driving cars can be outfitted with sensors that can see in the dark and detect when a deer is oncoming and brake beforehand or decide to shift lanes, as it would be aware if any other cars were near by, there will also be less of a delay in reaction than when a person is shocked and needs to respond. This reduction of delay also means an effective response would need to be arranged in a timely manner, the car could slow down, speed up, maybe even honk to alert the animal not to cross. This would also apply to moose. Additionally, the solution of putting up fences and trying to limit deer and moose movement only makes the issue worse as they can often get stuck on the highway between the fences and become disoriented, it also causes a shift in the habitat and lowers the population of the animals.

3. I believe this would be a good idea to implement on some major roads, and only when all cars are self driving. This will help severely limit severity of crashes, amount of reckless driving cases, and make the traffic system more predictable to help incorporate self driving cars more easily.
Although the lower speed limit would increase efficiency and safety, it would directly contradict with the performance aspect of highways and would limit the self-driving cars who can go faster speeds safely because of their technology. With strictly environmental considerations, this would make sense. However, considering other aspects of the PERSEID layers, people may not like this due to an increase of time for their daily commutes. Especially considering many people choose where they live

based on the time it takes to travel to work, a change like this would definitely make a difference to people's livelihoods. In terms of the environment, this change does make a difference but there are also better ways to reduce the carbon footprint of vehicles without changing speed limits such as designing a better infrastructure that has more public transit opportunities, making cities and towns more friendly for bikers and pedestrians, and even with adaptive cruise control algorithms that account for fuel economy when driving.

Our ideas:

- Children get into many accidents with vehicles, so should vehicles be banned from neighbourhoods with kids and schools? No ,this is not a good solution. A better solution is using sensors on self driving cars for kid collision detection.
- Parents run over their kids with cars in driveways, should cars be banned from driveways? No again, use sensors.
- Kids are more likely to be injured in cars, should kids be banned from cars? No, implement better tech into car seats and airbag technologies in the car

One thing that self-driven vehicles are better at than human drivers (in general) is fuel efficiency. For example, consider a driver ahead of you on the highway applying their brakes. How do you react in that split second decision? Maybe they are just decreasing their speed from 120 to 115, or maybe they are decreasing it from 120 to 50. It would seem reasonable to err on the side of safety and over-brake just in case, this effect cascades to the driver behind you now breaking a so on, leading to these highway *accordion* effects. On the other hand, self-driving vehicles have so many sensors and technology they can more accurately gauge the speed to brake to and not waste fuel.

We can begin to quantify energy (fuel) used by these vehicles, and in turn quantify our designs by noted the number or stops/restarts from rest, for example. Try to come up with some rudimentary physics models to describe the amount of energy it takes to brake a vehicle to a stop, and then restart it again. Feel free to research what others have done here, as well as other useful pieces of information like average vehicle weight, moment of inertia of a car wheel, etc.

Give some initial ideas/models below.

- One example of a design could consider existing sensors in the car including the OBD2 port on the car to read data such as how fast a car is decelerating and what velocity it is decelerating from/to along with vehicle weight along with the cars fuel economy to gauge how much fuel was wasted by stopping the car. Then we can calculate use this information again to calculate how much fuel was used to get the car back to a cruising speed again. We combine this information for all cars to give us a “total fuel used per minute”, which we can use to see at what point a design fails, and also to compare to other designs.
- The most simple model to describe the amount of energy it take to stop a car would be using kinetic energy, and with more detail this can include moment of inertias. To go from 0 to 100 km/h will take more energy than going from 0 to 50km/h, likewise, stopping from 100 to 0km/h requires more energy than 50 to 0. However, it is also important to note the time it takes to stop, if you are going from 80km/h to 60 km/h in 3 minutes vs. 10s, it will take much more energy to make that transition occur quickly. This basically models why stop and go traffic and abrupt stops that result from drivers who weave through traffic is not energy efficient methods of driving.

Here we are again, re-evaluate your designs/idea from the previous three weeks. Of your designs, which do you argue to be the best for the environment, which is the worst. Rank them and justify your choices below. It may be appropriate to use your physics models from the previous exercise. In addition to this, could you make any changes to your designs which would be beneficial to the environment?

1. Design 1 (two laned roundabouts) - This design would be the best for the environment as it eliminates the need for most cars to stop when the intersection is not busy, and there is no need for traffic lights, overhead electricity wires, traffic light maintenance installation, all of which reduces the intersections carbon footprint
2. Design 4 (Self-driving stop/yield sign system) - This is the second best as self-driving cars stop a minimum amount of times, reducing the amount of fuel wasted. This system however still has human driven vehicles stop and start each time, making it less efficient than the roundabout.
3. Design 3 (stop system with yield right turn lanes) - This design is the worst as human driven vehicles are the worst in terms of start/stop efficiency and how much fuel will be used and the amount of emissions produced

Over the past four design studios, you've reviewed four different design lens/layers: Performance, Socio-cultural, Regulatory, and now Environmental. Fill out the table below to summarize your work. This will aid in your Milestone 2 deliverable. Add additional comments where/if you see fit.

Design Choice/Factor	**Which layers are impacted? How?**	**How can you measure it?**

All cars be self-driven	Performance, self-driving cars keep the amount of stops to a minimum and increase the throughput of the intersection. Environment: self-driving cars have better communication therefore accelerating and decelerating will be calculated and achieve a better fuel economy (with charging)	Using throughput of the intersection in terms of cars per hour Using kWh (kilowatt hours) which is like fuel economy for gas vehicles
Self driving cars must be tested before driving	Socio-cultural/regulatory: this gives drivers on the road a sense of safety around self-driven cars as they know that they have been thoroughly tested and are road worthy	Doing surveys on drivers to ask how safe they feel on the roads Tracking, testing, and creating a standard
Self-driving cars are held to stricter road laws	Regulatory: laws must be implemented and revised to ensure self-driving cars are held to a stricter standard	The amount of laws passed involving self driving cars
Ensuring all self-driving cars have recyclable batteries	Environmental: Recycling the batteries will reduce the harmful toxins released into the environment if batteries go to landfills.	The number of batteries being sent to recycling vs landfills
Self-driving vehicles must be significantly	Environmental: Less use of electricity lessens the demand on electricity production to reduce the amount of non-renewable resources used for production of electricity	Tracking fuel efficiency by checking how long a charge lasts in different driving conditions

more fuel efficient		

Right now, your simulation records the amount of time it takes for a vehicle to pass through the system. If we wished to also document energy used by the vehicle (this could be an abstract placeholder for gasoline or electricity), how would you modify the code to achieve this?

Record the distance the car travels to the intersection, then passing through the intersection and use the electric or combustion motor efficiency to calculate the amount of power used. Then record the time spent accelerating (most fuel used) to calculate the total amount of electricity or gas used by the car.

Week 9: Self-Driving Infrastructure Activity 9

Overview and Goals

- Aggregate your individual decision matrices and arrive at a *final* design
- Organize your work to begin coding and simulating your final design

In your asynchronous activity you should have created a decision matrix for your designs. This required you to determine weights/scores for each cell/row. Moreover, some of you may have come up with additional rows/criteria to evaluate designs.

As a group aggregate all your matrices into a final matrix. As a team assign scores and weights to the cells and rows. This could be done by taking an average/total of what each group member did, or you can have an involved discussion to agree on what these parameters should be. As with the asynchronous activity, feel free to add your own rows and to consider more designs if you wish.

Criteria	Weight	Design 1: U-turn roads		Design 2: Displaced left turns		Design 3: Two-lane roundabout		Design 4: Cardinal directions	
Performance (throughput)	4	Score: 7	Total: 28	Score: 7	Total: 28	Score: 8	Total: 32	Score: 9	Total: 36
Acceptance Drivers (socio-cultural)	3	7	21	4	12	5	15	8	24
Acceptance Pedestrians (socio-cultural)	3	4	12	8	24	9	27	8	24
Safety (socio-cultural)	6	6	36	6	36	8	48	8	40
Regulation (meets laws or easy to change)	2	8	16	5	10	8	16	3	6
Greenhouse gas Emissions (environmental)	5	5	25	6	30	8	40	5	25
Construction (environmental)	1	8	8	6	6	7	7	2	2
Total	-	-	146	-	146	-	185	-	157

Was your winning design the one you anticipated it being? Give a few general comments below as to why you believe this design to be best, list some advantages (don't just say because it had the highest decision matrix score).

The two-lane roundabout scored the highest in the decision matrix and was a good design however, roundabouts are not scalable and do not really have more options for optimization, so we decided to go with a different design. The next highest score was the cardinal directions design, however after some discussion we decided it is too ambitious and requires to much construction to be implemented. It would not be deployable in many areas, and would have too high of a cost for some cities.

The final 2 designs were tied for last. These designs are the U-turn roads and displaced left turns. These are the most feasible designs and to decide between the two we are considering scalability, along with the PERSEID criteria. We are ultimately pursuing the displaced left-turn because it is the most feasible design and we believe the safety it provides pedestrians and cyclists is valuable.

Now that you have your design chosen, it is time to begin simulating and analysing it. Before that can be done however, you must write your simulation code. This is arguably the most technical and involved part of the project. Having said that, you are more than capable of achieving it.

Note: If you want to start (or continue) coding right this second, please do so!!! The rest of this worksheet is here if you are unsure where to begin.

Below is a table to organize your thoughts. Split your design into different *features.* A feature could be a lane dedicated to self-driven vehicles, a batch of n self-driven vehicles clearing the intersection very closely together, etc. Documents your features below:

Feature	Description	Code Strategy/Approach

Feature1	<description of feature1>	<how you plan to simulate feature1 in code>
Left turn yield lane	The lane left turning lane that allows cars to make a left turn. There is a yield signal that allows drivers to cross when it is deemed safe.	Queue that fills up with cars and cars are dequeued as they cross the intersection
Intersection, Traffic Light	The traditional intersection where cars are travelling through and obeying the traffic light	Function that creates a sequence of cars traveling through the intersection as cars travel through
Pedestrian crossing	Crossing that allows pedestrians to travel through the intersection	Queue and function that checks if the road is clear then allows pedestrians to cross

Within your simulation you will also be a number of parameters. These are things you can easily change: stop time, sate-travel-distance, time between arrivals, proportion of self-driven vehicles, etc.

Documents these parameters in the table below.

Parameter	Description	Potential Values to Test
Number of Lanes	The number of lanes that cars can go through not including the left turn lane	Low number of lanes and large number of lanes to simulate urban vs rural area
Light cycle timer	How long the left turn lane light stays on to allow left turning car to go	Short time and long time depending on how much use

		the left turn lane gets in that particular intersection
Pedestrian crossing time	How long the pedestrian crossing time allows pedestrians to cross	Short time and long time depending on how much use the left turn lane gets in that particular intersection
Left turn lane cycle time	How long the advanced left turn light allows a build-up of left turning lanes to turn	Short time and long time depending on how much many pedestrian use the intersection
Speed limit	The speed of the cars going through the inter section	Faster if more self driver cars and less pedestrians and slower if it is not safe to go a fast speed
Vehicle stopping time (self-driven)	How long it will take for a self-driving vehicle to come to a complete stop	Dependant how the car in front is slowing down and the traffic conditions
Vehicle stopping time (human)	How long it will take a human driven vehicle to come to a complete stop	More variability due to human impact but generally lie around the general traffic conditions
Left turning lane speed	How fast people turning left can go	Faster in safe conditions such as dry, good visibility road and slower if there is ice, snow etc.

It is unreasonable to expect you to be able to code this in the time allotted to the design studios. You will (almost certainly) need to work on this code outside of the studios. This will be a large chunk of the final deliverable. Take this time to discuss how you will manage your time, internal due-dates/timelines for your teammates, and who will be responsible for which parts (try not to dump this all on your software engineer – if you have one).

Document your decisions below:

We will first plan out all the modules needed for this project, what order we need them done in. We will have each group member work on one of these modules over the rest of this course and have a deadline for each module. This will eliminate difficulties in communicating code one group member does to someone else and worrying about them understanding it. With this, we treat each module like a black box that completes a task or gives an output without having to worry about implementation. Due dates and submission will be handled by one group member.

Week 10: Self-Driving Infrastructure Activity 10

Overview and Goals

1. Determine ways to verify your simulation code
2. Plan which experiments/simulations you will run

<u>How you spend the next two hours is totally up to you (in fact, it always has been). If you want to spend the entire time coding, go for it. Having said that, below are some exercises that you should be aware of once your code is complete.</u>

I know that after you write some code, your natural instinct is to assume it's correct – I mean, it's not like you make mistakes, right? However, it is required that we ensure our solutions do not contain errors. Some cases are easier than others. Imagine a simple function which takes two numbers and returns their sum. You could organize your test cases as below:

Input 1	**Input 2**	**Expected Output**	**Output Received**
-5	-10	-15	-15
0	0	0	0
6	10	16	16
-5	5	0	10

It should be clear that the function works at least some of the time, but maybe we should take a look at that last test case. What makes this function easy to test, is we know what the output should be. Now consider your road simulation code. What if you put all your parameters into your simulation and it spits out that the average response time is 2 minutes and 28 seconds. Is this number correct? …maybe?

The difficulty lies in the fact that the primary reason we run simulations, is because we don't know the answer. If we knew the answer, why would we run a simulation to begin with. But if we don't know what the answer should be, how will we ever determine if our simulation is correct? Well… you may never be able to 100% know if your code is correct or not (swallow that pill now), but we can certainly gain confidence that your code is correct.

First, we can run small simulations and make sure that the logic of your model is being followed. This can be tedious but is certainly useful (I had to do with for the first two simulation files I gave you – of course, there were no errors present). Be careful to make sure that these simulations are small enough to cope with, but long enough to hit interesting cases. For example, cars waiting at all directions of an intersection, a car stuck behind a slow driver but they cannot lane changed since some one else is in the other lanes, etc.

Second, we can use *sanity checks* of our model. That is, from analysis or instinct, we should know general truths for certain cases. If our simulation agrees with these cases we begin to believe in the other things the simulation tells us. For example, it should not take too much convincing to believe the following should hold:

1. As time between arrivals of driver decreases (more congestion) the response time of the system will increase
2. If time between arrivals is very large, a driver is likely to arrive to an empty system, and have a response time you can likely calculate from your model assumptions.

Document how you plan on verifying your simulations below:

4. Running test on the simulation using different test cases (eg. All lanes filled with many cars, each of the lanes filled, all lanes empty, one lane empty)
1. Running regular test and seeing how our simulation works on an average number of cars
2. We will have baseline speed and distance for the intersection for cars passing through. We will calculate this beforehand and use it to compare to other test cases.

For your final presentation you are expected you have some data/results to back up your claims. This may not be a full simulation suite of your final design (it could be), but could be some results from a portion of your simulations or other observations you made from your model/preliminary simulations.

On the other hand, for your final deliverable, you will be expected to have run potentially many simulations to demonstrate the behaviours of your design, and well as show insight to self-driving infrastructure. You should plan ahead of time what simulations you want to run, and how you will display this data to the reader. Taken from the asynchronous activity this week:

- *For example, you could run experiments where you change the proportion of self-driving vehicles. Maybe you run 11 simulations where the proportion of self driving vehicles = 0.0, 0.1, 0.2, … ,0.9, 1.0. And then graph average response time vs self-driven vehicle proportion.*

Think about the following:

3. What parameters/input can you change to your simulations?
4. What potential ranges of values would you like to simulate for each of these parameters?
5. What overall behaviour do you hope to show your model has? Use your instincts here, although remember, things don't always behave as you expect they should
6. How are you going to display this data in your final report?
7. Any other relevant questions you can think of.

Document the list of simulations you wish to run below (parameter combinations). How many simulations are you running total?

- How many lanes 1 each – 4 each?
- Different intersection designs? 3,4,5 etc dierctions?
- How many self driving vehicles? 0% - 100%?
- How many pedestrians? None to 50% as many cars
- How long signal is? 5 sec – 5 minute
- How long pedestrian signal is.
- Wait times between self-driving and human-driven should not vary too much

We hope this model has better performance for more self driving cars, and better performance for a les busy cars (longer interval between arrivals). Better performance for more lanes per direction

Using numbers of cars passing through each lane, time of simulation, # of self driving vs non self driving cars, # pedestrians, # lanes. All this data will be extracted from the code.

In our report we can obtain data from a variety of simulations and plot average wait times for the different road users depending on all the variables

Code

```java
public class Car {

    boolean selfDriving = false;
    int timeToCross;   //seconds, can represent speed eg. 5 seconds = 60 km/h
    int reactionTime;
    int speedUpTime;
    int stopTime;

    String test = "hi";

    public Car(boolean selfDriving) {
        if (selfDriving) {
            selfDriving = true;
            timeToCross = 3;
            reactionTime = 0;
            speedUpTime = 2;
            stopTime = 3;
        }
        else {
            timeToCross = 3;
            reactionTime = 3;
            speedUpTime = 2;
            stopTime = 3;
        }
    }

}
```

```java
import java.util.Collection;
import java.util.Iterator;
import java.util.LinkedList;
import java.util.Queue;

public class Lane {

    Queue<Car> Lane = new LinkedList<>();

    public void addHumanCar() {
        Lane.add(new Car( selfDriving: false));
    }

    public void addSelfDrivingCar() {
        Lane.add(new Car( selfDriving: true));
    }

    public boolean isNextSelfDriving() {
        if (!Lane.isEmpty())
            if (Lane.peek().selfDriving) {
                return true;
            }
        return false;
    }

    public void test(){
        int count = 0;
        for (Car i: Lane){
            System.out.println(count);
            count++;
        }

```

```java

    }


    public Car crossCar() {
        return Lane.remove();
    }

    public Boolean isEmpty() { return Lane.isEmpty(); }


    public static void main(String[] args) {
        Lane mine = new Lane();

        mine.addSelfDrivingCar();
        mine.addSelfDrivingCar();
        mine.addHumanCar();
        mine.test();
        mine.crossCar();
        mine.test();
    }


}

```

```java
public class SignalLight {

    int[] lights = new int[4];       //Directions represented as (N,S,E,W), 0 = red, 1 = green
    public SignalLight(){    //Initialize lights
        lights[0] = 1;
        lights[1] = 1;
        lights[2] = 0;
        lights[3] = 0;
    }

    public void LightCycle() {      //Call this function to change the light cycle
        if (lights[0] == 1 && lights[1] == 1 && lights[2] == 0 && lights[3] == 0) {
            lights[0] = 0;
            lights[1] = 0;
            lights[2] = 1;
            lights[3] = 1;
        }

        else if (lights[0] == 0 && lights[1] == 0 && lights[2] == 1 && lights[3] == 1) {
            lights[0] = 1;
            lights[1] = 1;
            lights[2] = 0;
            lights[3] = 0;
        }
    }



}
```

```java
import java.util.ArrayList;

public class Direction {

    int numberOfLanes;
    ArrayList<Lane> lanes = new ArrayList<>();
    Lane leftTurnLane = new Lane();

    public Direction(int numberOfLanes) {    //Initalize direction with all it's lanes
        this.numberOfLanes = numberOfLanes;

        for (int i = 1; i < numberOfLanes; i++) {
            lanes.add(new Lane());
        }
    }





}

```

```
public class Cycle {

    int cycleTime;
    int timePassedSubcycle;
    int timePassedTotal = 0;
    int numberOfLanes;
    double percentCongestion; //value for congestion between 0-1
    double percentSelfDriving; //value for selfDriving between 0-1
    //double percentLeftTurn = 0.2;
    int maxCarsInLane = 4;   //Value for the maximum amount of cars that can generate at once in a lane
    int numberOfCarsPassed = 0;

    Direction[] directions = new Direction[4];  //NSEW directions
    SignalLight light = new SignalLight();


    public Cycle(int cycleTime, int numberOfLanes, double percentCongestion, double percentSelfDriving) {
        this.cycleTime = cycleTime;
        this.timePassedSubcycle = 0;
        this.percentCongestion = percentCongestion;
        this.percentSelfDriving = percentSelfDriving;

        directions[0] = new Direction(numberOfLanes);
        directions[1] = new Direction(numberOfLanes);
        directions[2] = new Direction(numberOfLanes);
        directions[3] = new Direction(numberOfLanes);

        this.numberOfLanes = numberOfLanes;     //Generating all the lanes
        for (int i = 0; i < 4; i++) {
            directions[i].lanes.add(new Lane());

        }
```

```java
        }


    }
    public void generate(Lane lane) {    //enqueues cars into lane, taking into account %congestion and %selfDriving
        int numberOfCars = (int) ((double) maxCarsInLane * (percentCongestion));    //calculate total # cars depending on congestion

        double random;
        for (int i = 0; i < numberOfCars; i++) {    //adds ratio of self vs human cars based on %selfDrive
            random = Math.random();
            if (percentSelfDriving >= random) {

                lane.addSelfDrivingCar();
            }
            lane.addHumanCar();
        }
    }


    public void subCycle() {    //Generates cars for each lane in each direction, then lets batch through

        Car car1;
        Car car2;
        timePassedSubcycle = 0;


        while (cycleTime >= timePassedSubcycle) {

            for (Direction currentDirection : directions) {   //Generating cars for each lane in each direction
                for (Lane currentLane : currentDirection.lanes) {
```

```java
                for (Lane currentLane : currentDirection.lanes) {
                    generate(currentLane);
                }
                generate(currentDirection.leftTurnLane);    //Also for left turn lane
            }

            for (int i = 0; i < 4; i++) {   //Itterate every direction that has green light
                if (light.lights[i] == 1) {

                    if (percentCongestion <= Math.random()) { //Represent clearing in the road for car to turn left, more congestion =
                        if (!directions[i].leftTurnLane.isEmpty()) {
                            car1 = directions[i].leftTurnLane.crossCar();
                            timePassedSubcycle += (car1.reactionTime + car1.timeToCross);
                        }
                    } else {
                        for (Lane currentLane : directions[i].lanes) {

                            if (currentLane.isNextSelfDriving()) {   //If there is a self driving car at the front, let two cars cross
                                if (!currentLane.isEmpty()) {
                                    car1 = currentLane.crossCar();  //cross two cars and add cross time to total
                                    timePassedSubcycle += (car1.reactionTime + car1.timeToCross);
                                    numberOfCarsPassed++;
                                }
                                if (!currentLane.isEmpty()) {
                                    car2 = currentLane.crossCar();
                                    timePassedSubcycle += (car2.reactionTime + car2.timeToCross);
                                    numberOfCarsPassed++;
                                }

                            } else {    //If car is not self driving, only let one car through
                                if (!currentLane.isEmpty()) {
```

```java
                            if (!currentLane.isEmpty()) {
                                car1 = currentLane.crossCar();
                                timePassedSubcycle += (car1.reactionTime + car1.timeToCross);
                                numberOfCarsPassed++;
                            }
                        }
                    }
                }
            }
        }


        }
        light.LightCycle();
        timePassedTotal += timePassedSubcycle;
    }

    public int totalTime() {
        return timePassedTotal; }

    public int totalCarsCrossed() {
        return numberOfCarsPassed; }


    public static void main(String[] args) {
        Cycle test = new Cycle((60), numberOfLanes: 2, percentCongestion: 0.5, percentSelfDriving: 0.5);

        test.subCycle();
        System.out.println(test.numberOfCarsPassed);
        System.out.println(test.timePassedTotal);

```

```java


        for (int i = 0; i < 10; i++) {
            test.subCycle();
        }
        System.out.println(test.numberOfCarsPassed);
        System.out.println(test.timePassedTotal);


    }


}

```

Additional Material

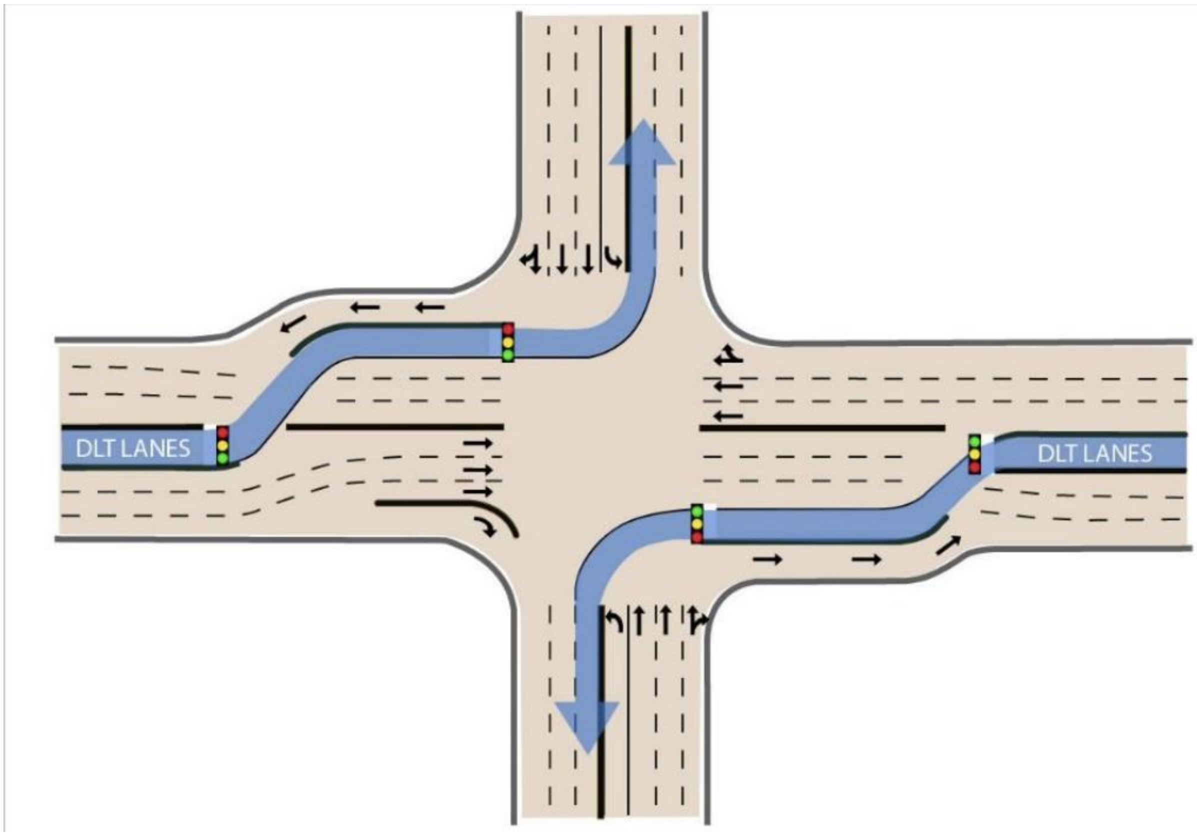

Figure X: Detailed drawing of the displaced left turn intersection

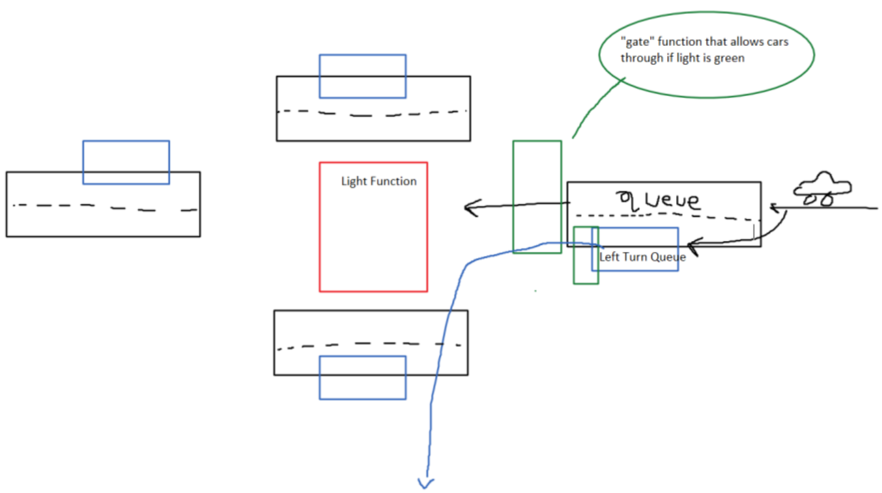

Figure X: Visualization of the simulated intersection