Self-driving Infrastructure: Milestone 2

Integrated Engineering Design Project 2: ENGINEER 2PX3

Design Studio 01

SDI-11

March 19, 2023

Harry Zihe Shi 400301295

Kush Rana 400405522

Teghveer Singh Ateliey 400409275

Michael Yip 400401586

Executive Summary

The purpose of this report is to provide an overview of the progress made through the feasibility analysis stage. The goal of this project is to redesign the traditional intersections in Hamilton with a self-driving infrastructure with various objectives relating to the performance of the system and algorithms which are discussed in the report. Through frequent meetings with the client and constant revision to the self-driving implementation, the team was able to improve the design. This report will highlight how the team is utilizing the PERSEID (Performance + Environmental + Regulatory + Socio-cultural screening for Engineering Integrated Design) method for engineering design [1]. It will discuss the impacts of self-driving infrastructure from an environmental, economic, ethical, and regulatory perspective which addresses some of the concerns of the client. This report will also highlight the varying emissions related to human-driven vehicles and self-driving vehicles. Furthermore, the current steps for the feasibility and implementation of the self-driving model are explained with a conceptualized simulation of the model with various alterations later described. Overall, this report provides a thorough overview of the feasibility and updates of self-driving infrastructure implementation at intersections.

Introduction

The self-driving infrastructure project is focused around improving the current automotive intersection to be aligned with the rising popularity of self-driving vehicles. Self-driving vehicles possess a vast number of smart features which are not synchronized and compatible with modern traffic intersections. Furthermore, current automotive intersections lack communication between vehicles and often create dangerous situations for drivers. For example, at a left turn signal, a driver may have difficulty seeing incoming traffic as it is blocked by vehicles on the other side of the road, waiting to turn. Additionally, there exists a lack of synchronicity between vehicles which causes a "Phantom effect" [2] which is when one driver fails to accelerate at a green light, causing the delay to compound and affect all the other cars that are waiting. The wide variety of safety and efficiency concerns posed by the current intersection design provides an opportunity for an innovative and new design with modern technology features. This teams self-driving infrastructure implementation aims to eliminate these problems through various focused solutions. To manage the ethical aspects of the system, the team has decided that the conservation of human life will always be the priority of the system when making decisions. For example, if the vehicle had to decide between hitting an unexpected pedestrian or swerving and hitting a tree, then the vehicle would do so. In order to mitigate the impacts on the environment, the team would also recommend the materials be sourced ethically and sustainably. Furthermore, the electric vehicles' dependence on electricity prompts the need for the source of that electricity to also be sustainable and renewable to limit emissions. The performance of this model will also be improved with the implementation of various sensors around the vehicle which can improve its spatial and environmental awareness along with the vehicle-to-vehicle technology which ensures streamlined data transfer.

Considerations Overview

Funnel Layer	Specific Considerations	Challenges
Technical Performance	*Vehicle Communication Capabilities:* Broadcasting critical information using V2X, V2I, and/or V2P. *3D-mapping and data visualization*: Generation of information of the vehicles in the intersection to improve locational awareness. *Traffic Volume:* Implementing wider roads, auxiliary turning lanes, and higher speed limits. *Traffic Signal Timing*: Designing an algorithm to limit vehicle type bias, possibly including signal control systems such as SCATS and SCOOT. *Private Sector Collaboration:* Companies such as Uber, Lyft, and Google can provide real time traffic data to optimize intersection controls throughout the day.	• Software exploitation vulnerabilities • Latency with current network technology • Signal interference from urban buildings (i.e., high-rises) • Competency disparity between self-driven and human-driven vehicles • Potential violation of privacy when collaborating with private corporations.
Socio-cultural	*Reaction time:* Self-driven vehicles have virtually no reaction time compared to human-driven vehicles; adjust simulation code. *Compactness and appeal:* A large, busy, and loud intersection may lower surrounding property value and be unappealing to residents. *Preference:* An intersection that has lower average travel times for certain vehicles may be seen as unjust or otherwise discriminatory.	• Reaction times of human drivers can vary widely. • Creating an appealing intersection can often conflict with performance. • It may be hard to eliminate preference

		in an intersection as self-driving vehicles are naturally more efficient.
Policy, Legislation and Regulation	*Adjusting speed limit:* Increasing the speed limit would presumably increase the average travelling velocity of vehicles. *Safety structures:* Railings, traffic signals, signs, and more must be considered to reduce collisions between vehicles.	• Collisions at higher velocities are generally more fatal. • The legislature is directly responsible for the infrastructure and any mistakes may reflect badly.
Environmental Impact and Resources	*Sustainable sources for materials:* Sustainable and resilient material can ensure a long-lasting system with minimal environmental footprint. *Idle time and emissions from vehicles:* The longer that vehicles stay in the system, the more emissions they will emit; tied to performance. *Urban sprawl and expansion:* A larger, more invasive intersection can threaten surrounding habitats and ecosystems.	• Incurring opportunity costs by implementing regulations to ensure ethical practices. • It is difficult to account for all effects on the natural area surrounding the intersection without month-long and year-long studies.

Table 1: Table of considerations of self-driving infrastructure

The challenges associated with each funnel layer is primarily the consequence of extrapolating data from our simulation and attempting to compare it with secondary data (i.e., simulation data from academic articles) to ensure its feasibility which can be difficult. In the technical performance layer, the vehicle communication capabilities are critical to facilitating limited stoppage at an uncontrolled intersection. The wireless nature of V2X, V2I, and V2P technologies inevitably poses software exploitation vulnerabilities. Exploitation risks can be reduced by deploying penetration tests and adjusting the security of the software accordingly. The 5G-NR network developed by 3GPP can transfer data with a latency of <1ms [3]. A low latency is important to ensure vehicles properly broadcast critical information, especially in an urban setting where high-rises are prevalent. Also, implementing directional antennas could avert signals away from zones of interference (i.e., high-rises) [4]. However, from the regulatory perspective, governing bodies are the entities to permit such technology and requirements (i.e., governing bodies may demand for a smaller latency rating). Translating the reaction times from our source code to the real-world is futile unless we randomize human reaction times. Self-driven vehicles can be homogeneous in reaction time because of their programmability and electric nature whereas human drivers can vary (e.g., drowsiness, age). Increasing speed limits is only possible if the governing body permits it. Collisions occurring at higher velocities in intersections are generally more fatal especially if it results in a T-bone collision. Since the current simulation source code does not result in collisions, it would be difficult to determine the feasibility (i.e., trade-offs) of increasing a typical urban speed limit of 40-50 km/h. Ensuring that the materials used in the system are resilient would minimize its carbon footprint.

Details of the Feasibility Study Considering the PERSEID Layers

Engineers have been trying to create the perfect intersection for years, yet the challenge of building infrastructure for self-driven vehicles is very new. The main challenge of building an intersection with autonomous vehicles is maximizing the benefits of self-driven cars while not ostracizing human-driven cars. This specific consideration was brought forward in the above section's socio-cultural layer. It will most likely be inevitable that self-driven vehicles will have a lower average travel time as a human-driven vehicle cannot match autonomous efficiency and coordination. This project will only be feasible if a discrepancy of average travel times between both types of vehicles is tolerated [1, 2]

Another socio-cultural consideration is compactness and appeal of the intersection. Many design decisions to improve performance may clash with the appeal of the intersection. For example, an extra lane may allow more cars in the system but reduce the greenery or sidewalk width that surrounds it. This project should not interfere or worsen the quality of life or property value of the surrounding area [3]. This concern can be feasibly satisfied by limiting the amount of concrete and asphalt used and utilizing green space and pedestrian paths wherever possible. The random times and randomness of human drivers also poses a challenge as it introduces more randomness into our system. This randomness will have to be accounted for by retaining elements of common intersections such as traffic signals and prioritization to maintain feasibility [2, 3].

SDI-11 has considered and proposed a variety of technical performance considerations to improve the intersection overall. Among these are 3D object mapping and V2X technology which allow the intersection to know where all participants of the system are located and better communicate with self-driven vehicles. However, software exploits, latency, building interference, and system failure present significant risks in using this technology [4, 5]. This project may not be feasible if any one technology is relied on too heavily, so all technologies should be heavily tested and equipped with back-up systems and redundancies to minimize error and catastrophic failure. Nonetheless, this technology will greatly improve the feasibility of this project in other aspects such as optimizing the travel times of human driven cars [5, 6].

Other considerations such as traffic volume and signal timing present similar challenges, in addition to a disparity of competency between self and human driven vehicles. Creating a more complicated system may induce more mistakes and randomness from human drivers. This may cause problems for autonomous vehicles which are not situated to certain circumstances. Implementing wider roads, turning lanes, higher speed limits, and optimizing signal algorithms can greatly increase the efficiency of the system [3, 6]. However, clearly defined lanes and paths, easy to spot directions and signals, and possibly a lower speed limit will all need to be used to have a feasible intersection for human drivers. This will need to be used in conjunction with V2X and object mapping to effectively locate and predict the paths of human drivers to direct them and the autonomous vehicles in the system [5].

Incorporating private sector aid into the infrastructure has also been considered for this project. This poses challenges in terms of privacy and regulation of data, as well as the privatization of public infrastructure. Implementation may bring an extraordinary ability for the intersection to predict and manage a variety of traffic loads at all times of the day. This will also be very feasible for the intersection, ultimately the decision to implement private sector data relies on how comfortable residents are with the proposal [5].

The responsibility of safety in this intersection falls directly onto policymakers and legislature. Regulation considerations include balancing the speed limit of the system. A faster speed limit may create a much more efficient intersection with lower travel times, yet a slower speed limit will ensure the safety of participants of the system and minimize collisions [7]. By running simulations and calculations, the optimal speed limit can be attained. Other considerations such as railings, signals, signs, and various safety structures have been brought forward. These structures present no significant concerns and must be included to obtain a feasible intersection [7].

The last funnel layer studied is the impact of the system on the environment and resources. Material selection is crucial to creating infrastructure that is resilient in all conditions while minimizing the environmental footprint of construction. Recycling used material into new infrastructure is currently the most optimal way to reduce material footprint, old building material and electronics can be repurposed, and sewage sludge can be mixed with asphalt [4, 5]. Opening design competitions at local schools for innovative ideas to reduce environmental impact through materials selection can be a great source of innovative ideas and feasible solutions [4].

Performance is tied with environmental concerns as many of the vehicles using the system will create greenhouse gas emissions. By sending these vehicles through the system as efficiently as possible, the emissions created may decrease. To achieve this, the distance travelled in the intersection for all vehicles should be kept to a minimum. Signal states should also detect waiting cars and allow them to pass through the intersections when it is safe, to minimize idle emissions. Another consideration is urban sprawl, primarily that a larger system can threaten surrounding environments and ecosystems. A solution to this can be relocating habitats or building the intersection vertically to prevent horizontal sprawl, hopefully in a way that does not impact birds.

The first client request was to graph the average travel time as a function of load on the system. In the source code, the arrival frequency is set to an arbitrary value for the number of vehicles that arrive at the intersection. A for loop was implemented to increment the load by 10 vehicles for each iteration. It was observed that setting a sufficiently high frequency, causes the behaviour of the trace to become distorted.

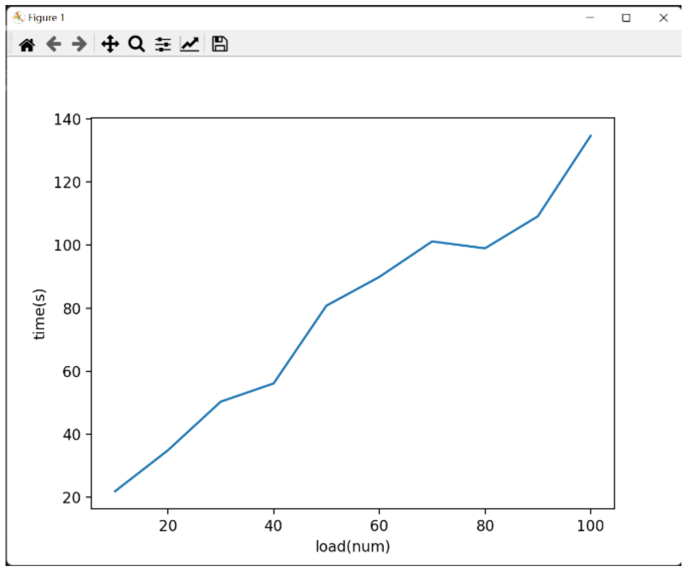

Figure 1. Plot of average travel time with respect to load.

By decreasing the frequency to 5 seconds, the function outputs a graph that makes sense, exhibiting an approximately linear behaviour. The second client request is two-fold; (1) we are to measure the estimated emissions for self-driven vehicles and for human-driven vehicles based on their proportionality of the traffic volume, and (2) measure the estimated emissions based on the type of driving (speed). The first part of the client request was achieved by utilizing the following fuel consumption (L/100km) formula: emission = round(0.0019 * self.speed*2 - 0.2506* self.speed + 13.74, 3) [9] where self.speed is a randomized parameter, and its range depends on the vehicle type. To improve the fuel economy, an optimal self.speed value must be assigned. Both plots for emissions versus the proportionality of human-driven and self-driven vehicles exhibit linear behaviours. As expected, as the proportion of human-driven vehicles increases, emissions increase. Conversely, as the proportion of self-driven vehicles increase, emissions decrease.

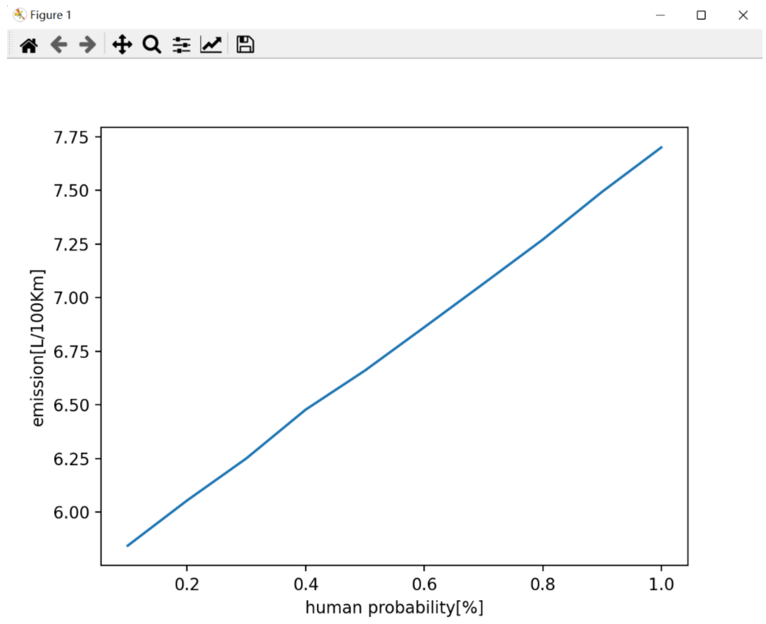

Figure 2. Plot of emissions with respect to human-driven vehicle proportionality.

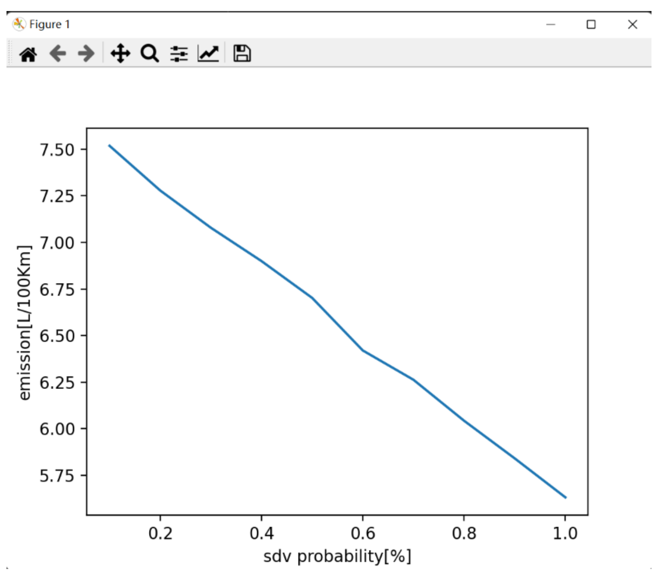

Figure 3. Plot of emissions with respect to self-driven vehicle proportionality.

It was assumed that human-driven vehicles are gasoline-powered while self-driven vehicles are fully electric. This is because self-driven vehicles need to capitalize on electricity as using an internal combustion engine results in greater latencies.

Conclusion

In conclusion, this paper outlines the efforts made by the self-driving infrastructure team 11 to design a junction to improve traffic efficiency and lower accident rates. This report outlined the steps taken to create a system for the intersection simulation using the PERSEID method. The technical specifications are defined, including how to model an intersection collision, V2X, 3D mapping, different sensors, calculations for emissions, and the intersection algorithm. The team wants to make the intersection more efficient in the future by enhancing vehicle awareness and the intersection's rules. Our team assesses the project via several factors, including technical performance, socio-cultural appropriateness, environment impact and regulation, and concludes that it the proposed design is highly feasible. This is a complicated procedure; therefore, we will keep adjusting the initial design, consulting with specialists as needed, and adapting it to satisfy any further customer needs.

References

[1] “2022-2023 Self Driving Infrastructure Project Summary,” class notes for ENGINEER 2PX3, Faculty of Engineering, McMaster University, Winter, 2023.

[2] What are phantom traffic jams?” Science ABC, 22-Jan-2022. [Online]. Available: https://www.scienceabc.com/eyeopeners/what-are-phantom-traffic-jams.html. [Accessed: 27-Jan-2023].

[3] M. Noor-A-Rahim, Z. Liu, H. Lee, M. O. Khyam, J. He, D. Pesch, K. Moessner, W. Saad, and H. V. Poor, “6G for vehicle-to-everything (V2X) communications ... - IEEE xplore,” *IEEE*, 20-May-2022. [Online]. Available: https://ieeexplore.ieee.org/document/9779322/. [Accessed: 18-Mar-2023].

[4] K. K. Nagalapur, E. G. Ström, F. Brännström, J. Carlsson, and K. Karlsson, “Robust connectivity with multiple directional antennas for vehicular ...,” *IEEE*, 09-Dec-2019. [Online]. Available: https://ieeexplore.ieee.org/document/8928957. [Accessed: 03-Mar-2023].

[5] Wei, Hua, Guanjie Zheng, Vikash Gayah, Zhenhui Li. "A survey on traffic signal control methods," arXiv [Online], vol. 1904, no. 08117, April 2019. Available: https://arxiv.org/abs/1904.08117

[6] Jee-Hyong Lee, Hyung Lee-Kwang, "Distributed and cooperative fuzzy controllers for traffic intersections group," IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews) [Online], vol. 29, no. 2, pp. 263-271, May 1999, doi: 10.1109/5326.760570. Available: https://ieeexplore.ieee.org/abstract/document/760570/metrics#metrics

[7] S. Kamijo, Y. Matsushita, K. Ikeuchi, M. Sakauchi, "Traffic monitoring and accident detection at intersections," IEEE Transactions on Intelligent Transportation Systems [Online], vol. 1, no. 2, pp. 108-118, June 2000, doi: 10.1109/6979.880968. Available: https://ieeexplore.ieee.org/abstract/document/880968

Wei, Hua, Guanjie Zheng, Vikash Gayah, Zhenhui Li. "A survey on traffic signal control methods," arXiv [Online], vol. 1904, no. 08117, April 2019. Available: https://arxiv.org/abs/1904.08117

[9] Song, G., Yu, L., & Wang, Z. (2009). Aggregate fuel consumption model of light-duty vehicles for evaluating effectiveness of traffic management strategies on fuels. Journal of Transportation Engineering, 135(9), 611–618. https://doi.org/10.1061/(asce)te.1943-5436.0000037

Appendix

Week 5 Meeting Minutes

Role	Name	Mac ID	Attendance (Yes/No)
Team Lead	Kush Rana	Ranak6	Yes
Administrator	Harry Shi	Shiz40	Yes
Coordinator	Michael Yip	Yipm10	Yes
Communications Liaison	Teghveer	Atelieyt	Yes
Client			Yes

Agenda Items

1. Take attendance
2. Share asynchronous components
3. Discuss potential modifications to infrastructure systems

Meeting Minutes

1. Content
    a. Review the effects of self-driving and gas-powered vehicles on the environment
    b. Review ethics of vehicle infrastructure
2. Lessons
    a. Review TA comments from previous studio
    b. Review technical memos and research

Post-Meeting Action Items

1. Consider TA comments for future reference
2. Continue working on milestone 2

Week 6 Meeting Minutes

Role	Name	Mac ID	Attendance (Yes/No)
Team Lead	Teghveer	Atelieyt	Yes
Administrator	Kush Rana	Ranak6	Yes
Coordinator	Harry Shi	Shiz40	Yes
Communications Liaison	Michael Yip	Yipm10	Yes
Client			Yes

Agenda Items

1. Take attendance
2. Share net worth assumptions with team members
3. Discuss how to integrate socio-cultural considerations into our analysis
4. Discuss and work on most recent client request
5. Complete synchronous worksheet for DS6
6. Meet and share progress with our valued client

Meeting Minutes

1. Code Analysis
   a. Experiments to run and parameters to test
   b. What are we confused about?
   c. What should we change/improve?
2. Deterministic and Non-Deterministic Analysis
   a. Compare two systems – consistent versus very efficient and very inefficient
   b. Deterministic values of simulation code
   c. Overall impact to performance
   d. Pseudocode for changes

Post-Meeting Action Items

1. Consider TA's question for future reference
2. Complete client request for next week
3. Complete asynchronous worksheets for Wk-7

Week 7 Meeting Minutes

Role	Name	Mac ID	Attendance (Yes/No)
Team Lead	Michael Yip	Yipm10	Yes
Administrator	Teghveer	Atelieyt	Yes
Coordinator	Kush Rana	Ranak6	Yes
Communications Liaison	Harry Shi	Shiz40	Yes
Client			Yes

Agenda Items

1. Take attendance
2. Share asynchronous documents with team members
3. Present client request
4. Present progress presentation

Meeting Minutes

1. Synchronous worksheet
    a. Discuss about the socio-cultural layer of the PERSEID methodology
    b. Expected values comparisons for different socio-cultural factors such as priority, time, etc.
2. Lessons/Insights
    a. Learned that we were rewarding self-driven vehicles rather than human-driven vehicles by virtue of reaction time

Post-Meeting Action Items

1. Consider TA's question for future reference
2. Start preparing for client request #2
3. Technical memo
4. Finish and submit synchronous worksheet by Sunday

Week 8 Meeting Minutes

Role	Name	Mac ID	Attendance (Yes/No)
Team Lead	Harry Shi	Shiz40	Yes
Administrator	Michael Yip	Yipm10	Yes
Coordinator	Teghveer	Atelieyt	Yes
Communications Liaison	Kush Rana	Ranak6	Yes
Client			Yes

Agenda Items

5. Take attendance
6. Share asynchronous documents with team members
7. Present client request
8. Present progress presentation

Meeting Minutes

1. Synchronous worksheet
    a. Discuss other factors regarding safety with self-driven vehicles
    b. Re-evaluate designs from a regulatory/safety viewpoint
    c. Review the simulation ideas to incorporate crashes
2. Lessons/Insights
    a. We re-examine the meaning of life and the importance of safety

Post-Meeting Action Items

1. Consider TA's question for future reference
2. Finish and submit synchronous worksheet by Sunday
3. Start and finish Milestone 2