Intersection for Autonomous Vehicles

The typical intersection in North America has some deficiencies related to traffic flow. In current intersection designs, human-driven vehicles cannot synchronize their acceleration rate when the traffic light turns green due to human reaction time [1]. Causing a ripple effect that is intensified by increased traffic volume, leading to phantom traffic jams [2]. The majority of vehicle accidents in the United States in 2016 were caused by human errors, according to a report from the National Highway Traffic Safety Administration (NHTSA). Therefore, prioritizing the safety of road users is crucial when designing an intersection, even if it impacts traffic flow.

The project client requested a redesign of an intersection in Hamilton to accommodate both human and self driven vehicles using only localized features. With the assumption that the ratio of human to self-driven vehicles will be 1:1 due to advancements in self-driving technology, the intersection will prioritize traffic flow and safety with user satisfaction in mind [1]. However, the team is not responsible for software development; random machine errors will not be considered. The self-driving infrastructure project aims to reduce traffic congestion, ensure road safety, and use traffic sensors, faster signal activation, collision prediction, and more to enhance overall satisfaction [3].

Additional Stakeholders

Stakeholders in this project other than the client include the government or regulating body of the area, self and human driven vehicle occupants, and vehicle manufacturers. Pedestrians are not a focus for this project, but it was decided that pedestrians and cyclists will be another stakeholder [1, 3]. Vehicles, pedestrians, and cyclists are most obviously impacted by self-driving infrastructure as they physically participate in it. It is anticipated that their primary concern would be the safety of the intersection, with a secondary concern being the performance of the intersection as measured by wait times.

Object Mapping in Self-Driving Infrastructure

Object mapping is a critical aspect of autonomous vehicles and their interaction with the environment. It is used to create a digital representation of the surrounding environment, enabling the vehicle's sensors and processing units to identify and track different objects such as pedestrians, cyclists, and other vehicles [3]. In the context of intersections, object mapping can be used to detect other vehicles, improving safety, and traffic flow. Since human-driven vehicles cannot communicate directly with infrastructure, object mapping can be used by the intersection to determine the positions of these vehicles [4].

Object mapping involves creating a digital model or “map” of the environment using a combination of sensors, cameras, and other technologies [4]. The process typically involves scanning the environment, detecting objects, and creating a 3D map of the surrounding area. This map is then used to inform the vehicle's decision-making, such as determining the optimal path to take, identifying potential obstacles, and predicting the movement of objects in the environment [5]. The accuracy of the object mapping system is critical to the safety and reliability of the system, especially in the context of intersections where safety is the highest priority.

Usage of Object Mapping

In an intersection, object mapping can be used to detect the density of human-driven cars and predicting the likely destination of these vehicles. This information can be used to change the signal phase of the intersection to relieve traffic congestion efficiently. Object mapping can also track the wait times of vehicles, helping the intersection decide which vehicles should go next [3]. Along with this, human drivers often make unpredictable decisions such as sudden lane changes, which can lead to accidents and traffic congestion. By detecting human-driven cars, autonomous vehicles can anticipate their movements and adjust their behavior accordingly [5, 6].

One approach to detecting human-driven cars is to use machine learning algorithms. These algorithms can be trained on a dataset of human-driven cars, allowing the system to recognize and track them in real-time. For example, a system could be trained to detect the shape and movement patterns of human-driven cars, enabling it to distinguish them from other objects such as pedestrians and cyclists [6]. This approach has the potential to improve the accuracy and reliability of object mapping systems in detecting human-driven cars.

Another approach to detecting human-driven cars is to use dedicated sensors such as LiDAR or radar. These sensors can detect the shape, velocity, and distance of objects in the environment, providing detailed information that can be used to identify and track human-driven cars [6]. For example, LiDAR sensors can create a high-resolution 3D map of the environment, enabling the system to accurately detect and track human-driven cars in real-time [3, 6]. This approach has the advantage of being less dependent on machine learning algorithms, making it more reliable and less prone to random machine errors.

Drawbacks of Object Mapping

There are certain challenges associated with using object mapping in intersections. One of the main challenges is the need for high-resolution sensors and processing units. The accuracy and reliability of object mapping systems depend on the quality of the sensors and processing units used [3, 6]. High-resolution sensors and processing units can be expensive, making it challenging to implement object mapping systems on a large scale. Additionally, object mapping systems require significant computing power, which can be a limiting factor for intersections in tight areas without additional space for equipment.

Feasibility of Object Mapping

Object mapping technology is an essential component for intelligent intersections that can improve safety and traffic flow. In the context of this project, human-driven cars are unable to communicate with directly infrastructure. While the self-driven vehicles do have this capability, the benefits of vehicle-to-infrastructure communication is not as impressive if only half of the intersection's vehicles are capable of it. To assess the feasibility of implementing object mapping technology in an intersection design project, a thorough examination of the PERSEID screening process, stakeholders, the current development of object mapping, and a comparison of simulation results is necessary [1].

The PERSEID method identifies the key parameters that must be considered when conducting the simulation. These parameters could be deterministic values such as mean arrival time, stop time, and clear time, which can be adjusted based on regulations such as speed limits. However, socio-cultural factors such as reaction time have not yet been integrated into the source code, as the project team is not responsible for the technical aspects of the project [1]. Nevertheless, pseudocode has been created that implements an if statement to assign reaction constants accordingly.

The environmental parameters that have been analyzed include idle time and the area of concrete and pavement relative to shrubbery. To address the idle time issue, an uncontrolled intersection has been proposed. After completing the first client request of plotting the average travel time against the load using a specific for loop, it was observed that the trace follows approximately linear behavior. Empirically, the relationship was better than anticipated. Figure 1, shown below, illustrates the average travel time as a function of load on the system, with load being defined as the number of vehicles at the intersection.

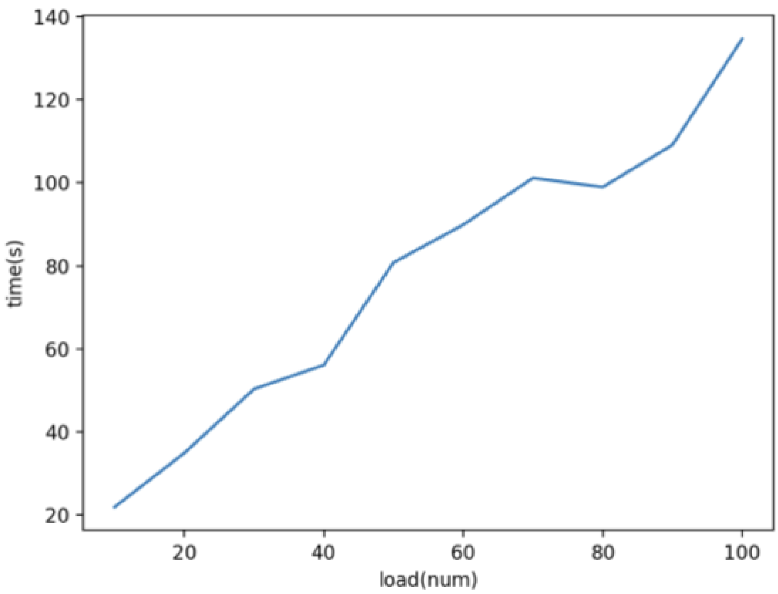

Figure 1: Average travel time of vehicles using the intersection versus load.

At a load of 20, the average travel time is ~35 seconds, while at a load of 100, the average travel time is ~130 seconds. Since the graph appears to follow linear behavior, it is expected that at a load of 100, there should be an average travel time of ~175 seconds, but the above simulation results fall below that. To implement object mapping in the simulation, the locations and intentions of all vehicles were known to the intersection as if it were mapping vehicle objects. This finding suggests that object mapping technology in an uncontrolled intersection is indeed feasible.

In conclusion, the feasibility of implementing object mapping technology in an intersection design project hinges on the PERSEID screening process, stakeholder involvement, current developments in object mapping, and simulation results. The PERSEID method provides a framework for addressing key parameters such as environmental, socio-cultural, and regulatory factors, while stakeholder involvement ensures that their concerns are considered. The pseudocode developed for socio-cultural factors, such as reaction time, demonstrates that they can be incorporated into the source code. Finally, the simulation results show that object mapping technology in an uncontrolled intersection is feasible and can improve traffic flow and safety.

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] J. Gwak, J. Jung, R. D. Oh, M. Park, M. A. K. Rakhimov, and J. Ahn, "A review of intelligent self-driving vehicle software research," KSII Transactions on Internet and Information Systems, 30-Nov-2019. [Online]. Available: http://itiis.org/digital-library/22283. [Accessed: 26-Jan-2023].

[4] 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

[5] 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

[6] 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