Optimized Campus Transportation

P2 Final Report

APSC 200/293

MTHE

Faculty of Engineering and Applied Science

Queen's University

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Date of Submission: 03/12/2023

Statement of Originality

Our signatures below attest that this submission is our original work.

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

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Lucas Musselman	Problem Definition, Citations	Introduction, Discussion	Edited all sections of the report
Luke Gaylor	Project Plan, Appendix, Citations	Conclusions, Recommendations, Executive Summary.	Edited all sections of the report
Lucas Komljenovic	Statement of Originality, Background Information, Objectives and Constraints, Final Design Solution, and Final Design Assessment	Introduction, Discussion	Edited all sections of the report

Executive Summary

Queen's University students contend with harsh winters, creating challenges in navigating cold and icy conditions. Despite the university providing safety tips, the increased potential risk of accidents still persists, particularly in low-traffic areas. This project aims to design an optimized transportation system to address these concerns, while confronting student challenges, such as time-consuming commutes, and loss of motivation in winter months. This is done by employing Lloyd's algorithm to optimize shuttle bus routes. Stakeholder needs are central to the project, encompassing affordability, accessibility, reliable infrastructure, and environmental sustainability.

The active stakeholders in this project consist of the Queen's University student body, the shuttle bus retailer, the Kingston City Council, and the design team, while passive stakeholders include local residents, the university administration, and environmental groups such as Sustainable Kingston. Each group has specific interests and considerations tied to the development of an optimized shuttle system. The student body prioritizes affordability, accessibility, and real-time updates, while the shuttle bus retailer must meet Kingston transit standards. The City Council ensures regulatory compliance and addresses potential traffic impacts. The design team collaborates with stakeholders to create a high-quality transportation system. Local residents seek minimal disruptions, and the university administration monitors system adherence to values and policies. Environmental groups emphasize sustainability goals.

The team delves into the rationale behind the development of the new shuttle system, addressing issues related to inefficient public transit for students. The team justifies the system's design by examining potential cost savings, emission reductions, and its impact on student wellness. The decision-making processes, including a mind map, weighted evaluation matrix, and the implementation of the SCAMPER tool, are thoroughly discussed. The final design, comprised of the shuttle and navigation subsystems, is outlined in detail. This includes operational considerations, shuttle attributes, and associated costs.

Economic considerations are presented, focusing on shuttle costs, labour, operational expenses, technology integration, infrastructure, regulatory compliance, and a contingency budget. A cost analysis comparing the annual expenses of a proposed hybrid shuttle design with a diesel alternative is included, prioritizing environmental benefits despite a slightly higher cost.

Environmental considerations take precedence, aligning with Kingston's commitment to climate change mitigation. The suggestion to invest in public transit emerges as a means to limit greenhouse gas emissions. Designing a shuttle system will not only align with the university's environmental objectives but will also provide a valuable asset to the student community. The proposed solution also adheres to the triple bottom line framework, and it involves the development of an optimized shuttle system exclusive to Queen's University, enhancing accessibility and safety.

Future recommendations are provided, emphasizing expansion to other universities and potential commercialization. The team proposes a phased approach, adapting the software for different settings to validate effectiveness, with the end goal of creating a start-up or partnering with a tech giant.

In summary, this report outlines a comprehensive initiative to address the transportation challenges faced by Queen's University students during harsh winters. The proposed solution involves the development of an optimized shuttle system, integrating a modelling algorithm to inform shuttle-drivers with their most optimal route. This initiative aligns with environmental sustainability, stakeholder interests, and meets the needs of the university community.

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1. Introduction

1.1 Background Information

Students at Queen's university annually face harsh winters that leave sidewalks, crosswalks, and public paths covered in slippery ice and snow. The university's website provides, "winter safety tips", but despite their efforts, the high risk of extreme winter conditions causes students to become injured every winter [1]. The universities efforts to mitigate winter risk is not exhaustive enough to prevent injury. For example, high traffic areas are prioritized for snow and ice removal, leaving low traffic areas vulnerable to an increased potential for accidents [1]. This research aims to develop an understanding of how climate, infrastructure, and transportation might influence a solution for getting students to campus safely.

1.1.1 Student Living and Transportation

In 2009, a study was conducted by eight graduate students at the School of Urban and Regional Planning at Queen's University, which outlined the estimated living areas surrounding Queen's university, for off-campus students [2] . Although this study is outdated, the research group displayed a projected living area map for students in years to come, resulting in a more accurate representation of current student living areas. Figure 1 below displays off-campus student housing, within a black border [2]. Pink and red areas are excluded from the student population because they represent campus, Queen's buildings, and the downtown.

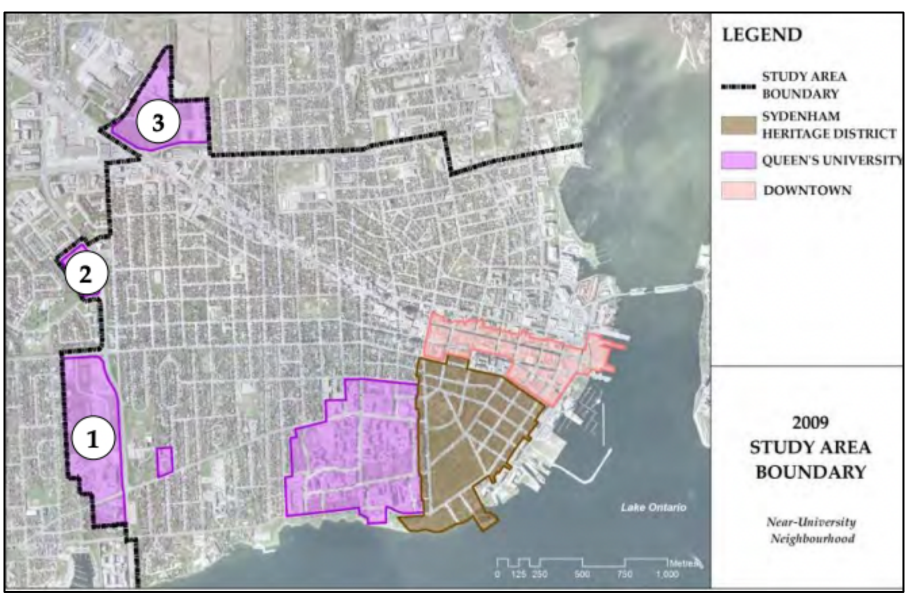

Figure 1: The map above displays the projected living area for students off-campus given by a 2009 study [2].

For students living on the outskirts of the above region, the 25+ minute walk can be unsafe due to the weather, walking conditions, and time of day. Therefore, public transit or personal vehicles are often used to reduce risk, as well as to get to campus faster. The primary mode of public transportation serving the campus and its vicinity is the Kingston Transit bus system [3]. Figure 2 below illustrates the bus system that covers the student living area [2] [3]. Coloured road lines depict routes taken by buses, within the student living area [3].

Figure 2: The map above displays the routes of the Kingston Transit bus system in the surrounding areas of Queen's University [3].

When comparing Figure 1 and Figure 2, a lack of bus routes throughout the estimated student living area can be seen. Many of the heavily student populated areas, such as Nelson St. and University Ave., lack accessible bus routes and stops [3]. Since the Kingston Transit bus routes are not solely entitled to Queen's University and their students, their current routes are optimized for the casual city-goer, which does not necessarily match the needs of the students. Therefore, there is a need for an optimized shuttle system solely for Queen's University and its students and staff.

1.1.2 Climate and Infrastructure

An optimal shuttle system would be able to go from campus to the student population instantly, taking little resources. As the time and resources that this process takes increases, the system becomes less efficient and provides less benefit to students. Thus, by understanding how winter weather, and Kingston infrastructure effects road travel, solutions can be implemented to reduce delays, allowing the shuttles to travel as quickly as possible. This section thus explores how a shuttle system is influenced by climate and infrastructure.

First, the impact of winter climate is discussed. Hazards derived from winter driving come from five categories: compromising surfaces, blocking and damaging infrastructure, compromising visibility, compromising steering, and creating obstacles [4]. Examples of hazards associated with each category, as well as the causality that hazards from one category can have on another are outlined in **Error! Reference source not found.** below.

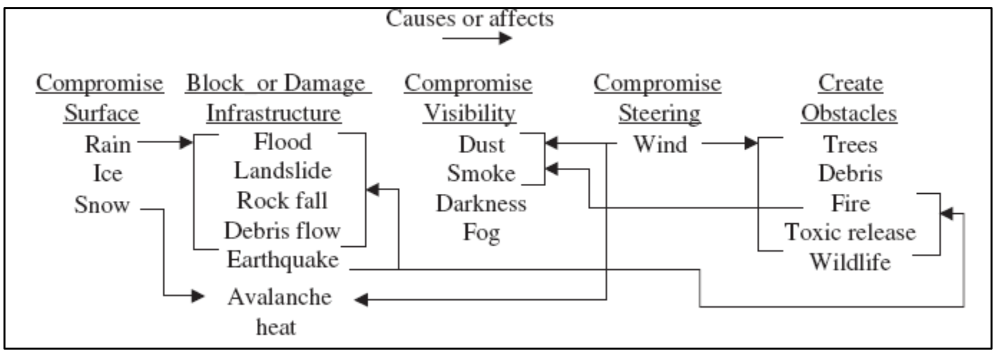

Figure 3: Categories of winter hazards, including examples and causality [4].

The shuttles must be designed so that when these hazards occur, the effect that they have on the operation of the shuttles is minimized. Regarding surface hazards, skidding is the most common cause of accidents, which is caused by rain, ice and snow [4]. Rain roughly doubles the percentage of accidents where skidding is a factor, and thus the shuttles should reduce speed by a third on wet roads and by a half on snowy and icy roads, and utilize winter tires, which minimizes these accidents [4] [5]. Poor visibility is another source of hazard, which is addressed utilizing panoramic side mirrors to eliminate blind spots, having heaters and defrost equipment, as well as heavy-duty windshield wipers [6]. A third category of hazard is compromised steering, which can be mitigated by a power-assisted steering, which reduces response time between the driver and the shuttle [7]. Regarding the two remaining categories of damaged infrastructure, and created obstacles, this does not influence design of the shuttles, but is rather mitigated by having an efficient navigation system that can provide routes to avoid damaged infrastructure.

To conclude the background research, interactions between climate, infrastructure, transportation, and students have been explored. On the path of going from understanding to solving, the problem is defined next.

1.2 Problem Definition

This section of the report defines the problem that the design team intends to solve. Additionally, this section breaks down the unique needs of the stakeholders and indicates the scope of the project.

1.2.1 Problem Statement

Students at Queen's university often commute between campus and their housing several times each day. These commutes can be extremely time consuming over the course of a semester and induce high stress levels, especially for students living on the outskirts of the student housing area. Moreover, the cold Kingston winters can reduce student motivation to attend classes for those who do not have access to transportation such as a car or bicycle. The objective of this project is to provide a safe means of travel to school for students living off campus. This will be done by designing a transportation system that utilizes Lloyd's algorithm to generate shuttle bus routes which are optimized to reach the maximum number of students and transport them to class. Through this objective, the project hopes to benefit all facets of the triple bottom line: planet, by taking cars off of the road and reducing greenhouse gas emissions; people, by providing an equitable transportation service for queen's students; and profit by creating a system that is able to generate enough money to pay for its own expenses.

1.2.2 Stakeholders

Active stakeholders for this project include the Queen's university student body, the shuttle bus retailer, the Kingston City Council, and the design team. Passive stakeholders include local residents, the university administration, and environmental groups such as Sustainable Kingston.

The Queen's student body is comprised of more than 31,000 undergraduate and graduate students [8]. Of these students, approximately 99% study on the Kingston campus [8]. These students have a vested interest in the design of an efficient and reliable shuttle bus system to transport them to campus throughout the school year. It is imperative that the service be affordable and accessible for all, including those with disabilities or financial difficulties. The service must also feature convenient access to transportation hubs and should consider the development of an app to distribute real time updates on bus schedules and routes.

The shuttle bus retailer is a key stakeholder in this project since it must supply the vehicles and infrastructure which will transport the students to campus. As mentioned in section 2.3.1 Shuttle Costs, the team considered two options for acquiring shuttle buses for this service including partnering with an established company and directly purchasing the shuttles. Ultimately, the team opted to purchase the shuttles from a retailer, making the retailer a significant stakeholder. The company must provide a reliable fleet of vehicles that are well-maintained and meet Kingston transit vehicle standards.

Kingston City council is the municipal governing body of Kingston and is responsible for delivering community services including construction, environmental sustainability initiatives, and transit. The city council has a stake in the project because the shuttle service would enhance the quality of life for the residents of Kingston. As such, the city council must ensure that the system abides by the applicable regulations and policies related to transportation such as the Kingston Transportation Network Company Bylaw [9]. Additionally, since the project may influence traffic patterns in the city, the city council has a stake in managing traffic flow efficiently and minimizing disruptions.

Another key stakeholder is the design team of engineering students from Queen's who have the responsibility of designing the public transportation system. Throughout the design process, the team must engage with various stakeholders to ensure alignment with their requirements. To deliver a high-quality design, the team must secure adequate funding and establish a realistic project timeline. Furthermore, the team needs access to essential resources for conducting thorough research and gathering data on commuting patterns to optimize the transportation system effectively.

Further Stakeholders include the local Kingston residents who are directly impacted by changes in traffic patterns and transportation infrastructure. The project's design should aim to minimize disruptions to their daily lives and maintain or improve their overall quality of life, while ensuring community safety. The Kingston residents also require timely updates concerning route or scheduling changes that may impact traffic flow in their neighbourhoods. Involving the public throughout the project can help address moral and ethical concerns and demonstrate a commitment to responsible practices.

The Queen's university administration is another passive stakeholder who is responsible for ensuring that the transportation system enhances the well-being and convenience of its students. The administration is responsible for ensuring that the system adheres to the Queen's university EDII values, which includes developing appropriate accessibility and inclusivity measures. Moreover, the system must incorporate effective feedback measures to monitor the success of the system and address issues. The administration should also ensure that the project adheres to internal university policies, guidelines, and standards.

Finally, Kingston environmental groups are concerned about the impact of transportation systems, including factors such as air pollution, carbon emissions, and noise pollution [10]. Sustainable Kingston is a partner of Queen's and is committed to reducing greenhouse gas emissions. As such, the shuttle system must establish clear sustainability goals and monitor its success over time.

1.2.3 Project Scope

The scope of the project needs to be realistic, achievable, and must consider time, budget, and other constraints. The team is constrained by the available technology that can be used to track shuttles in real time and provide updates regarding the location of the shuttles to students via a mobile application. Furthermore, the team must comply with any applicable regulations and transportation guidelines established by the Kingston city council. Other constraints such as stakeholder coordination and the experience of the design team will impact the scope of the project. As such, the team opted to design a shuttle service featuring two subsystems, those being the shuttle and navigation subsystems, further described in section, 2.2 Final Design. The team also opted to focus on providing the service during winter months which is when hazards are most likely to occur but is also the time at which students most desire transportation to campus. Lloyd's algorithm allows the most optimal bus routes to be calculated based on the population density of student housing. However, due to the inexperience of the design team with MATLAB, the agents in Lloyd's algorithm move in straight lines from their original location to the high-density areas. The scope of the project does not include coding the agent paths to follow Kingston roads according to the Kingston road map. As such, these routes will not stay within the roads. However, the routes can easily be manually altered by the team after they are determined by the algorithm to follow the nearest road. Moreover, the project scope does not include the consideration of Kingston traffic patterns. Additionally, the scope does not include determining some specific cost estimates such as sustainability initiative costs and regulatory compliance costs. Furthermore, the team elected to design a system that considers a static population density based on the location of student housing at the beginning of each semester. If the university decided to implement this system, the team would recommend considering changing student locations throughout the day based on lecture hall student densities.

1.2.4 Objectives, Design Criteria, and Constraints

Having explored constraints imposed by infrastructure, climate, and Lloyd's algorithm on the shuttle system in 1.1 Background Information, a list of project objectives can be designed. This list of objectives must sate these needs whilst fulfilling stakeholder requirements described in Section, 1.2.2 Stakeholders. Table 1 below outlines objectives for both the shuttle and navigation subsystems, including details on where each requirement has been derived from.

Table 1: Set of objectives for the shuttle and navigation subsystems. The table outlines how each objective was decided upon, as well as the impact of the objective on the triple bottom line. Green indicates a positive impact, and red a negative impact.

Shuttle Subsystem				
Objective	Triple Bottom Line			Derivation of Objective
	People	Planet	Profit	
Shuttles must be environmentally friendly.				Queen's is committed to taking local action against climate change [11].
Shuttles must be equipped with technology to mitigate hazards of compromised surfaces, visibility, and steering.				The chance of skidding, the most common type of accident, is doubled with compromised surfaces due to rain and snow [4].
Shuttles must be designed to fit 70 students, and there must be 10 of them.				Ontario road laws limit inter-city buses to have a maximum of 70 passengers [12]. Also, 1 bus per 1,000 population is common practice, and an estimated 10,000 students are prospected to use the shuttles **[13]**.
Shuttle system must generate income to cover its expenses.				The university is facing an operating budget deficit of $62.8 million [14].
Navigation Subsystem				
Navigation system must be operational over the 5 by 5 km region described in Figure 1.				The detailed region is the estimated off-campus living area for students according to a 2019 study [2].

Navigation system must transmit to each shuttle the destination it must go to according to a density map.				This corresponds to the capabilities of Lloyd's algorithm, and will get students to campus safely [15].
The density map that the stops are decided according to must be interchangeable.				To serve the most students with the least amount of energy consumed, routes must be optimized to a density map reflective of the year.

2. Discussion

Having explored the issues incurred through poorly designed public transit for students, the potential cost savings, emission reductions, and student wellness that the new shuttle system will provide is clear, justifying its design. The decision-making processes used throughout the project and final design of the shuttle system is now discussed, followed by a comprehensive evaluation of project economics, ethics, and environmental impact. The final design is then assessed against the table of objectives in section,

1.2.4 Objectives, Design Criteria, and Constraints.

2.1 Decision Making

Before finalizing the decision to implement a shuttle system, a mind map was created to consider a broad range of potential solutions to optimize a transportation service to and from campus. The comprehensive mind map can be found in Figure 5 of the Appendix. The mind map considers the possibilities of implementing an Uber-like service, a carpool service, or an optimized bike and walking route, in addition to the shuttle system. To narrow the potential solution options from the mind map, the team decided to implement a weighted evaluation matrix, which can be found in Table 2 below, to decide on a final design solution. Since the project required the selection of the final solution early in the project's timeline, the weighted evaluation matrix was deliberately kept simple and straightforward. The criteria that the potential solutions were evaluated on include inclusivity, effectiveness, and the effectiveness of modelling the design using a multi-agent system. The team assigned weights to three criteria in accordance with the primary project requirements, which centered around modeling a design utilizing a multi-agent system. Consequently, the efficacy of modeling through a multi-agent system received the highest weighting, accounting for 50 out of 100 points. In addition, both the inclusivity and effectiveness of the design were assigned equal importance, with both criterions achieving a weighting of 25 out of 100 points. The equality of these weightings is justifiable as the proposed design must satisfy both effectiveness and inclusivity requirements, ensuring alignment with the resolution of the stated problem and fulfillment of functional needs. The weightings of all three-design criterion were kept simplistic, as this decision was made at the beginning of the project's timeline.

The scores for each potential design in the weighted evaluation matrix were given by directly referencing the rubric in Table 4 of the Appendix. The rubric highlights the definition of each score, which ranges from 1 to 5, relating to each criterion. Additionally, the rubric provides comprehensive examples, as well as highlighting the proposed design that corresponds directly to each score with a brief explanation. For example, in the "Effectively Modelled using a Multi-Agent System" row of the rubric found in Table 4, the "Score of 5" column states that the proposed design will achieve a score of 5 if it can be effectively modelled using a multi-agent system and can be simulated using either the Consensus or Lloyd's algorithms. For example, a shuttle service that carries passengers on fixed routes which are determined by the density of students in the given area. Moreover, when traversing through Table 4, the justification for each score that corresponds to a potential solution will be evident, as concrete examples are given and explanation is provided.

In summary, the weighted evaluation matrix for the potential solution selection is provided in Table 2 below. As stated above, the scores are given by directly referencing the specific explanation and highlighted examples provided in the rubric in Table 4 of the Appendix. The total score for each potential design is also provided in the bottom row of Table 2 below.

Table 2: The table below shows the weighted evaluation matrix that was used to evaluate the potential solutions to optimize a transportation service to and from campus.

			Potential Solutions to Optimize Transportation Around Campus			
	Criteria for Decision-Making	Weight (%)	Shuttle System	Uber-Like Service	Carpool Service	Optimized Bike/Walking Route
1	Inclusivity	25	4	4	3	5
2	Effectiveness	25	5	4	3	2
3	Effectively Modelled using a Multi-Agent System	50	5	4	2	3
	Total	100	4.75	4	2.5	3.25

Referencing the total scores above, the shuttle system achieved the highest score of a 4.75 out of 5, with the Uber-like service being second with a score of 4 out of 5. The team then compared these two potential solutions on if they could be modelled in a multi-agent simulation using either Lloyd's algorithm or the Consensus algorithm, as required by the P2 project's outline [15]. The team believed that the Uber-like service would be difficult to model using either of these two algorithms because of the multiple routes that the vehicles will take given the large number of different customers. In contrast, the team believed that the shuttle service could be easily modelled using a multi-agent simulation using either Lloyd's algorithm or the Consensus algorithm because the shuttle service would carry passengers on fixed routes which could be determined by the density of students in the given area. Therefore, because of the increased complexity of modelling the Uber-like service, the team decided to select the shuttle system as the final design solution.

Next, the team implemented the SCAMPER decision making tool by referencing how the Kingston Transit service could be improved on. The team choose the improvement of the Kingston Transit service because it shares many similar features to a shuttle system, such as overall functionality and area coverage. The 1.1.1 Student Living and Transportation section of this report further displays the necessity for enhancing the Kingston Transit service. The implementation of SCAMPER is displayed in Figure 6 of the Appendix, where the SCAMPER template was provided by the APSC 200 workshop material [16]. Through completion and inspection of the SCAMPER template, a better understanding of what needed to improve and how a reworked shuttle system could be implemented was obtained. For example, in Figure 6, the Modify section states that one could modify the Kingston Transit design to be more environmentally friendly, by considering electric or hybrid vehicles to reduce the carbon footprint. This modification relates directly to the first project objective highlighted in Table 1 above; therefore, it is evident by the team that it should be implemented into the final proposed design of the shuttle system. Moreover, the SCAMPER template in Figure 6 was referenced throughout the project to make core decisions such the implementation of hybrid vehicles for the shuttle system.

Finally, the team was set on the use of a density map to represent the student living data. The selection of a density map was made because it can utilize the Gaussian distribution function, which is a sufficient way to model density over an area [17]. Because of this sure choice to use a density map to represent student living data, the selection of the correct algorithm was a trivial choice as only Lloyd's algorithm uses a density map in its simulation [15]. Therefore, because of the selection of a density map to model the student living data, Lloyd's algorithm was selected for modelling the multi-agent shuttle system.

2.2 Final Design

The final design consists of two subsystems, the shuttles, and the navigation system. These systems work together to deliver a complete system for transporting students to and from campus, making the journey to campus safer during the winter. This system balances the triple bottom line impact, through optimization strategies in both subsystems. The shuttle system is discussed first, followed by the navigation system. For each subsystem, a description is given, followed by justification.

2.2.1 Final Design: Shuttle Subsystem

10 shuttles will be operational, each shuttle will have 70 passenger seats, and be equipped with the following attributes: hybrid engines; winter tires; panoramic side mirrors; heaters; defrost equipment; heavy-duty wipers; power steering; 30% reduced speed in wet conditions; and 50% reduced speed in snowy and icy conditions. The shuttles will operate from 8:00am to 11:00pm, which corresponds to Queen's classes, which run from 8:30am to 9:30pm. The shuttles will service the target region depicted in Figure 1, and will only allow Queen's students as passengers.

The shuttles will be stored overnight at the Kingston bus depot and be staffed by employees of the Kingston Public Transit. The net expense is estimated to be $1,658,000 per year, derived in section 2.3 Economics, and a corresponding fee of $53 will be added to each student's tuition in order to cover all yearly expenses associated with the shuttles.

The number of shuttles operational is derived from an estimated 50% of the 20,950 students living in off-campus housing being projected to use the bus service [18]. This along with the 1 bus per 10,000 population regulation means 10 shuttles must be in service [13]. The choice of each shuttle having 70 passengers is made to satisfy Ontario's passenger road laws, which includes the regulation that a city bus must have no more than 70 passengers [12]. The attributes decided upon for the shuttles are chosen because they are the best strategies to minimize the chance of delay due to compromised surfaces, visibility, and steering [5] [6] [7]. Further justification of the final design can be found in sections: 2.3 Economics; 2.4 E; 2.5 City of Kingston Environmental ; and 2.7 Assessment of Final Design. Also, the design of contingency plans is outlined in section 2.6 Safety, Risk Management. The navigation system is described next.

2.2.2 Final Design: Navigation Subsystem

A server located on Queen's campus will be running the navigation algorithm. The navigation algorithm takes as inputs each shuttle's current position and uses a density map along with Lloyd's algorithm to compute an optimal destination for each shuttle. It then transmits this data to each shuttle, where the destination is fed into google maps, to provide the driver with clear instructions on where to drive. This density map will be created each year based on a school-wide survey gathering locational data on where students are living. The figures below show examples of density maps, and the Lloyd's algorithm being run on each unique density map, to generate destinations for the 10 agents.

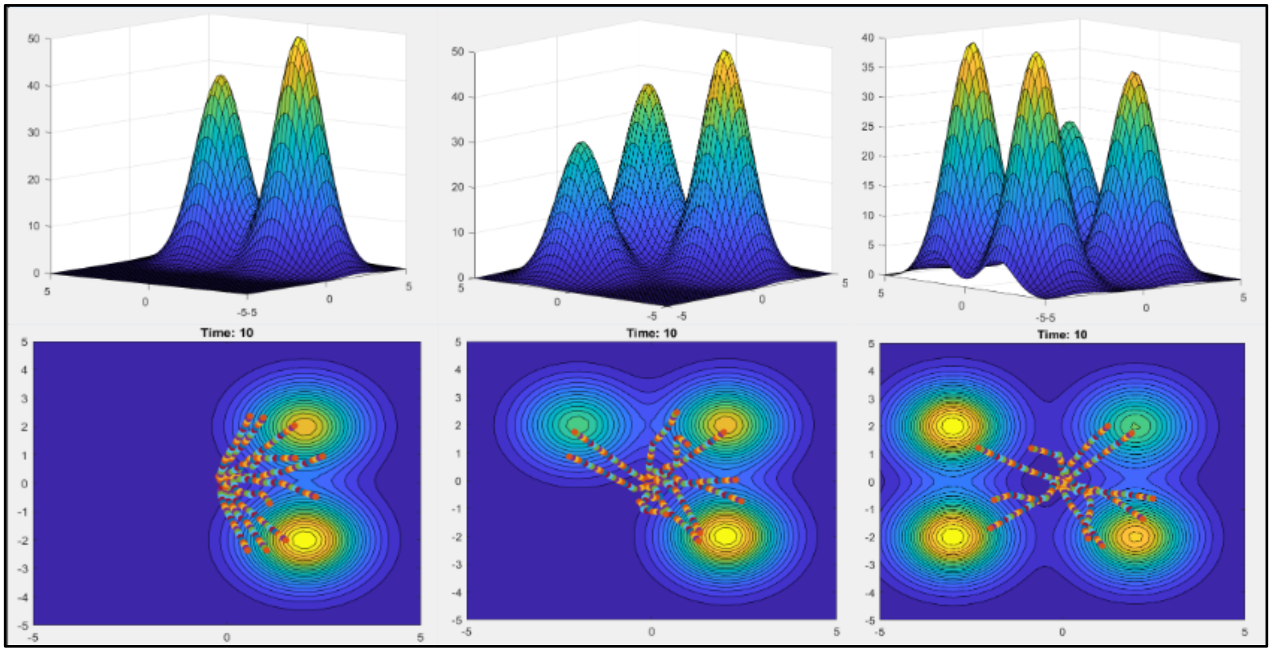

Figure 4: In the top row, three different density distribution maps are shown, representing distribution of the student population over the target region. Below each graph, the simulation is run on the respective distribution. This generates locations for each of the 10 shuttles to navigate to.

After a given shuttle reaches its destination, it will return to the campus shuttle hub, where it will drop off students. The server will then compute a new destination for the given shuttle. The shuttle will then broadcast its next destination, so that students can board to go to that location. The system then repeats continuously during operation times. An app will be made for the students to track shuttle movement and pick-up destinations; however, design of this app is outside of project scope.

The navigation algorithm was designed in MATLAB to meet objectives outlined in section

1.2.4 Objectives, Design Criteria, and Constraints. Detail on how each criterion is met is discussed in section 2.7 Assessment of Final Design. The overall subsystem has been designed to provide a more just service system for students, that utilizes student density, as opposed to the needs of the working class, to decide routes. This makes the shuttle system a better choice for students than Kingston Transit.

2.3 Economics

This section breaks down the economic considerations taken by the team throughout this project. It also explains how certain economic factors influenced project decisions.

2.3.1 Shuttle Costs

There are a variety of shuttle bus sizes and types that are suitable for different types of cities and services. Proper selection of bus size and fuel type is essential to ensure proper functionality and maximize service quality. However, these decisions can only be made after considering the demand for each service routes, fuel costs, and emission levels. There is a lack of information regarding the population distribution of students living in student housing. The team will assume that there are three particularly dense areas as indicated by the average of the three simulated density maps in section 2.2.2 Final Design: Navigation Subsystem. If three shuttle busses are sent to each location, Queen's would require nine total shuttle busses. The team will assume that 10 shuttles are needed to account for the possibility of a vehicle breakdown.

The team has explored two alternative approaches to acquire the shuttles: forming a partnership with an established shuttle service or direct purchase of buses. Due to constraints on available resources, the team was unable to determine the cost to partner with a shuttle company in the Kingston area. The benefits of this option include immediate access to a fleet of buses, experienced drivers, and lower upfront costs. However, the university may have limited control over operational aspects of the service and the team expects the long term costs to be high compared to alternative options.

Ultimately, the team opted for the direct purchase approach because it allowed for a more thorough analysis. However, the team now faced the decision of choosing between hybrid and diesel buses. Based on 2011 values in the US, the purchase cost of a conventional 40 ft diesel bus ranges from \$280,000 to \$300,000 compared to a hybrid bus that is between \$450,000 and \$550,000 [19]. The total cost to purchase 10 diesel shuttles is estimated below:

$$\frac{\$290{,}000}{diesel\ shuttle} \times 10\ diesel\ shuttle = \$2.9M$$

Similarly, the total capital to purchase 10 hybrid shuttles is calculated below:

$$\frac{\$500{,}000}{hybrid\ shuttle} \times 10\ hybrid\ shuttle = \$5M$$

The American Public Transit Association (APTA) defines the lifetime of a transit bus as 12 years. Based on this lifetime, the annual cost of a diesel shuttle disregarding the time value of money is \$241,667. Similarly, the annual cost of a hybrid shuttle is \$416,667. Although the capital cost of hybrid transit buses is approximately 50% to 70% more than conventional diesel buses, the anticipated fuel savings mentioned in section 2.3.3 Operational Costs (Fuel, Maintenance, and Insurance) and the environmental benefits associated with hybrid technology discussed in section 2.5 City of Kingston Environmental Considerations compelled the team to select hybrid buses [20].

2.3.2 Labour Costs

The salary of a bus driver working for the city of Kingston ranges from $25.60 to $31.42/hour. The team will assume that the shuttle drivers are paid a conservative average of $30/hour and that 10 shuttles are operated continuously between 8:00am and 8:30pm. Assuming that there are 260 workdays during any given year, the total labour costs can be approximated below:

$$\frac{\$30}{hr} \times \frac{12hr}{day} \times \frac{260day}{year} \times 10shuttles = \$936{,}000/year$$

2.3.3 Operational Costs (Fuel, Maintenance, and Insurance)

To approximate the cost of fuel for the shuttles over the course of a year, the team considered the cost of diesel to be $1.785/L as reported by the Government of Ontario on November 27, 2023 {Citation}. The fuel efficiency of a bus is influenced by various factors, including the vehicle load, traffic, road condition, and driver behavior. To gain a baseline estimate of fuel costs, the team disregarded these factors. One study reported that the fuel cost of conventional diesel buses was $0.79/mile whereas hybrid buses cost about $0.62/mile to fuel [6]. Considering the distance between student housing and campus, the team approximated the average shuttle route distance to be 1km long in each direction. Additionally, the Team assumed that each shuttle makes a round trip prior to the beginning of each half-hour between 8:30am and 8:00pm. This allowed the team to calculate an estimate for the annual diesel cost.

$$\frac{0.79\$}{mile} \times \frac{1.6mile}{km} \times \frac{2km}{trip} \times \frac{24trip}{day} \times \frac{260day}{year} \times 10\ shuttles = \$157{,}747/year$$

By a similar calculation, the estimated annual hybrid fuel cost is $123,802/year, approximately 22% less.

Based on the APTA lifetime of 12 years, an assessment conducted by the International Journal of Life Cycle Assessment in 2015 determined that the total maintenance cost of a diesel bus including insurance is approximately $444,000 which corresponds to an annual cost of $37,000. In comparison, the lifetime maintenance cost of a hybrid bus was found to be $337,420, or $28,118 per year [6].

2.3.4 Technology Integration Costs

Due to constraints on the available technology and project timeline, the team was unable to accurately determine the cost to develop an application that provides students with live updates regarding the location of the shuttles. Software development companies including Crowdbotics and Let's Nurture report that it would cost approximately $20,000 to $50,000 to develop a transportation app. The team will assume that this cost is $35,000. Although this is a capital cost, the app may need updates every few years and as such can be estimated to be divided by the shuttle bus lifetime of 12 years. This results in an annual cost of $2,917.

2.3.5 Infrastructure Costs

The team considered constructing bus shelters at the most densely populated areas near student housing. However, the team recognized that the population density of students will inevitably change each year as students move in and out of housing and even between semesters as students travel for exchange. As such, there is a high probability that the most densely populated locations will change, shifting the bus stop locations accordingly. The team decided that signs would be placed at the established bus stop locations, resulting in a negligible annual cost.

2.3.6 Regulatory Compliance Costs

Regulatory compliance costs include those related to meeting emissions standards, safety requirements, vehicle licensing, and driver training. Many of these expenses are outside of the scope of our project and must be determined by the university if intends to pursue this project further. The team expects that these costs will be relatively small compared to the total project cost. As such, the team will ignore these costs in the final cost analysis.

2.3.7 Contingency Budget

The contingency cost is a provision set aside in the budget to account for unforeseen expenses that may arise during the course of the project. These expenses could result from fuel price fluctuations, regulatory changes, emergency response measures, customer feedback enhancements, or legal disputes. It is common practice for projects allocate 5-10% of the total budget towards the contingency budget. To be conservative, the team determined that an annual 10% of the total budget would be sufficient.

2.3.8 Total Cost

Below, in Table 3, is a detailed cost analysis for the proposed shuttle design. The table compares the cost of a hybrid shuttle design against the cost of a diesel shuttle design.

Table 3: Cost Analysis of the proposed shuttle design

Cost	Annual Hybrid Cost (in thousands CAD)	Annual Diesel Cost (in thousands CAD)
Shuttle Costs	$416.7	$241.7
Labour Costs	$936	$936
Fuel Costs	$123.8	$157.7
Maintenance/Insurance Costs	$28.1	$37
Technology Integration Cost	$2.9	$2.9
Total (before contingency)	$1,507.5	$1375.3
Contingency Budget (1.1x)	$150.8	$137.5
Total (after contingency)	$1,658.3	$1,512.8

Although the annual cost for the hybrid shuttle approach is estimated to be $145,500 more expensive than the diesel alternative, the team prioritized the environmental benefits of the hybrid shuttles over the slight economic advantage of the diesel shuttles. Furthermore, the team is optimistic that environmental groups such as Sustainability Kingston who is a partner of Queen's University will offer some funding to reduce the price difference between the two shuttle options.

2.3.9 How to acquire necessary funding?

As indicated in section 1.2.2 Stakeholders

Active stakeholders for this project include the Queen's university student body, the shuttle bus retailer, the Kingston City Council, and the design team. Passive stakeholders include local residents, the university administration, and environmental groups such as Sustainable Kingston.

The Queen's student body is comprised of more than 31,000 undergraduate and graduate students [8]. Of these students, approximately 99% study on the Kingston campus [8]. These students have a vested interest in the design of an efficient and reliable shuttle bus system to transport them to campus throughout the school year. It is imperative that the service be affordable and accessible for all, including those with disabilities or financial difficulties. The service must also feature convenient access to transportation hubs and should consider the development of an app to distribute real time updates on bus schedules and routes.

The shuttle bus retailer is a key stakeholder in this project since it must supply the vehicles and infrastructure which will transport the students to campus. As mentioned in section 2.3.1 Shuttle Costs, the team considered two options for acquiring shuttle buses for this service including partnering with an established company and directly purchasing the shuttles. Ultimately, the team opted to purchase the shuttles from a retailer, making the retailer a significant stakeholder. The company must provide a reliable fleet of vehicles that are well-maintained and meet Kingston transit vehicle standards.

Kingston City council is the municipal governing body of Kingston and is responsible for delivering community services including construction, environmental sustainability initiatives, and transit. The city council has a stake in the project because the shuttle service would enhance the quality of life for the residents of Kingston. As such, the city council must ensure that the system abides by the applicable regulations and policies related to transportation such as the Kingston Transportation Network Company Bylaw [9]. Additionally, since the project may influence traffic patterns in the city, the city council has a stake in managing traffic flow efficiently and minimizing disruptions.

Another key stakeholder is the design team of engineering students from Queen's who have the responsibility of designing the public transportation system. Throughout the design process, the team must engage with various stakeholders to ensure alignment with their requirements. To deliver a high-quality design, the team must secure adequate funding and establish a realistic project timeline. Furthermore, the team needs access to essential resources for conducting thorough research and gathering data on commuting patterns to optimize the transportation system effectively.

Further Stakeholders include the local Kingston residents who are directly impacted by changes in traffic patterns and transportation infrastructure. The project's design should aim to minimize disruptions to their daily lives and maintain or improve their overall quality of life, while ensuring community safety. The Kingston residents also require timely updates concerning route or scheduling changes that may impact traffic flow in their neighbourhoods. Involving the public throughout the project can help address moral and ethical concerns and demonstrate a commitment to responsible practices.

The Queen's university administration is another passive stakeholder who is responsible for ensuring that the transportation system enhances the well-being and convenience of its students. The administration is responsible for ensuring that the system adheres to the Queen's university EDII values, which includes developing appropriate accessibility and inclusivity measures. Moreover, the system must incorporate effective feedback measures to monitor the success of the system and address issues. The administration should also ensure that the project adheres to internal university policies, guidelines, and standards.

Finally, Kingston environmental groups are concerned about the impact of transportation systems, including factors such as air pollution, carbon emissions, and noise pollution [10]. Sustainable Kingston is a partner of Queen's and is committed to reducing greenhouse gas emissions. As such, the shuttle system must establish clear sustainability goals and monitor its success over time.

1.2.3 Project Scope, there are approximately 31,000 students attending Queen's university, most of which pay full tuition to attend the school. The team proposes that Queen's administration divides the total cost of the shuttle service among all students, resulting in a yearly tuition increase of just over $53 per student yearly.

2.4 EDII

This section outlines how the proposed final design displays EDII practices. The shuttle system is designed to serve the entire population of Queen's University. This ensures equal access for all students regardless of their residential locations or transportation challenges, contributing to the university's equity goals. The shuttles are not accessible to general residents of Kingston, however since the shuttles only travel to and from campus, there is no foreseeable need of general residents to use the shuttle. This along with the fact that Kingston Transit offers transportation to campus for general Kingston residents, means that excluding non-students from the shuttle service serves no ethical harm. The proposed solution is diverse as the shuttle system acknowledges the diverse demographics of the student body by accommodating a significant number of passengers per shuttle, being 70. The consideration of varied commuting habits and the provision of a shuttle service that operates until 11:00 pm align with the diverse schedules and lifestyles of all Queen's University students and staff. The decision to limit shuttle services to Queen's students fosters an inclusive environment for the university community, however students outside of the shuttle's target region may unfortunately miss out on benefitting from this service. This could hopefully be improved on in the future by creating a specific shuttle system for each residential area of Kingston that is open to all residents. The inclusivity is further emphasized through the consideration of inclusivity features like priority seating, clear aisles, and storage zones, ensure that all students, including those with distinct mobility needs, can comfortably and safely utilize the service. Finally, while the final design does not have any specifications that directly benefit indigenous communities, an approach to enable indigeneity could be to consult with indigenous stakeholder's, specifically the Anishinaabe, Haudenosaunee and the Huron-Wendat nations [19]. These consultations would consist of how the team could properly acknowledge the operation of the shuttle system on this shared land [19].

2.5 City of Kingston Environmental Considerations

The City of Kingston places significant importance on taking proactive measures against climate change [10]. Recognizing the firsthand impacts of climate change, such as hotter summers, warmer winters, and increased iciness, the City emphasizes the crucial need to reduce greenhouse gas emissions [10]. The City of Kingston, as outlined on its official website, recommends measures such as increased investment in public transit and the limitation of personal vehicle use in urban environments [10]. Because the proposed shuttle system design is to be situated around Queen's University, which is located in the City of Kingston, these guidelines were considered during the design process of this project. The proposed final shuttle design, with its improved accessibility and inclusivity for students and staff, fosters an increased investment to and utilization of public transit. This investment will be incorporated into the annual tuition, a mandatory payment made by every student each year. More information regarding how much will be added to each student's tuition is referenced in section 2.3 Economics of this report. Additionally, the shuttle system design is tailored to the density distribution of students across campus locations, ensuring an accessible transit route. Due to the costs associated with gas and personal vehicle maintenance, the enhanced accessibility of the shuttle system is expected to result in reduced personal vehicle usage. Therefore, the shuttle system offers a more cost-effective and equally accessible alternative to personal vehicle usage. Moreover, the proposed final design aligns with the suggestions made by the City of Kingston to reduce greenhouse gas emissions.

The proposed final design aligns with the triple bottom line framework, providing profitability while concurrently benefiting individuals and the environment. The preceding paragraph outlines the positive impacts on individuals and the environment, emphasizing the reduction of greenhouse gas emissions and improved access to public transit. Additionally, the design presents an opportunity for university profit, as the shuttle service's cost will be seamlessly integrated into marginal increases in each student's tuition. Specific design choices for reducing environmental impact are discussed in section 2.7 Assessment of Final Design.

2.6 Safety, Risk Management, and Professionalism

Although the shuttles are designed to withstand extreme winter weathers, there is still a risk of delay in service due to inclement weather. This section aims to outline contingency plans, as well as factors to increase safety in the case of emergency. Possible delays can arise from two types of incidents: internal and external. Regulations to minimise internal incidents will be discussed, followed by regulations for external incidents.

Internal incidents are situations within the shuttle that could cause delay; this includes problems with shuttle equipment, systematic issues, such as overcrowding, and behavioural issues. The shuttle will comply with Kingston Transit regulations to minimize these incidents and to make the bus as safe as possible for passengers. A full list of regulations can be found on the city of Kingston's website, however some examples include: giving priority to passengers in need of mobility aid; offering storage for bulky items as to not block the aisles; banning smoking on the shuttles; and clear announcements of shuttle stops for passengers in need of hearing aid [20].[22]. Another internal incident could arise if the navigation system fails to work, in this case, the driver should go to its original destination, return to campus, and then service normal Kingston Transit lines, as to not back up the need for students to get back home. Once the navigation is back online, the shuttle should travel to the end of its line, and then return to campus to offer its normal service. This plan for addressing internal incidents will result in a respectful environment on board, contributing to the project's goal of offering safe transportation for students.

External incidents are situations outside of the shuttle that could cause delay; this includes problems with the exterior of the shuttle, as well as problems with Kingston infrastructure or weather. To operate the shuttle system, many Ontario regulations must be met, this includes: The Highway Traffic Act, Dangerous Goods Transportation Act, Public Vehicles Act, Motor Vehicles Transport Act, Compulsory Automobile Insurance Act, and the Environmental Protection Act [21].. To satisfy these regulations the shuttles must undergo regular inspections by technicians, daily driver inspections, spot checks, and yearly audits [21].[23]. This will make sure that the exterior of the shuttle is always service-ready. In the case of delay of service due to weather, supplementary shuttles can be introduced to pick up backed-up service. However, since the choice of 10 shuttles was decided upon considering student population, supplementary shuttles should only be needed in the most extreme cases.

2.7 Assessment of Final Design

With a complete understanding of what the shuttle service entails, it can now be assessed against the set of objectives outlined in Table 1, from section

1.2.4 Objectives, Design Criteria, and Constraints. First the shuttle subsystem is assessed, followed by the navigation subsystem.

Regarding the shuttle system, there are four criteria for assessment. The first criterion is that the shuttle must be environmentally friendly. This objective is satisfied through the choice of running the shuttles on hybrid engines. Carbon emissions of hybrid busses are 1,068g/mile compared to the 2,680g/mile of gas buses [22].Carbon emissions of hybrid busses are 1,068g/mile compared to the 2,680g/mile of gas buses [24]. By having students opt to take an eco-friendly shuttle instead of driving to campus independently, Queen's University will be contributing towards their sustainability goals as a part of the Sustainable Kingston initiative [11]. The second objective is that the shuttles must be equipped with technology to mitigate hazards of compromised surfaces, visibility, and steering. To fulfill this need, the shuttle is equipped with winter tires, panoramic side mirrors, heaters, defrost equipment, heavy-duty wipers, and power steering. The way in which these technologies reduce the risk of accidents is thoroughly described in section 2.2.1 Final Design: Shuttle Subsystem. The third objective is that there must be 9 shuttles, each with a maximum capacity of 70 students. This objective is met and improved upon through the choice of having 10 shuttles: 9 to be operational at a given time, and 1 supplementary shuttle in the case of service delay or shuttle breakdown. The final objective is for the shuttles to provide no expense for Queen's University, as mentioned in section 2.3 Economics, the system will provide no cost for Queen's. Overall, the shuttle system meets and exceeds the project expectations.

Moving onto the navigation system, three objectives are assessed. Firstly, the navigation system must be operational over the 5 by 5 km target student living region described in Figure 1. As shown in section 2.2.2 Final Design: Navigation Subsystem, the inputted distribution map and outputted navigation directions cover the entire target region, satisfying this criterion. Also, the navigation system is expandable, such that it can easily be altered to cover larger areas in the case of project expansion in the future. The second objective is for the navigation system must be able to communicate to each shuttle its respective destination. The decided upon system satisfies this by using a central server on Queen's to transmit google maps data to each shuttle corresponding to their respective destination. The final objective is for the density map to be interchangeable. In section 2.2.2 Final Design: Navigation Subsystem, it is demonstrated that the navigation system is operational on any distribution map, and three examples are shown. Thus, all objectives for navigation system are met. Overall, the project is successful. Project outcome is discussed next in section 3. s.

3. Conclusions

The team has achieved a milestone in the successful development of an optimized shuttle system. This is evident through all design criteria from the objectives table, Table 1, being satisfied, as well as a successful live simulation executed in MATLAB. The primary aim of the project was to identify a pertinent real-world issue that could benefit from the use of Consensus or Lloyd's algorithm and devise a practical solution. The strategic decision to tackle challenges within public transportation systems in university towns exemplifies the team's farsightedness, ensuring relevance and a direct application of Lloyd's algorithm. This focused strategy enhances the project's overall impact and underscores its potential for future scalability.

Expanding on this success, the team's creative solution looks to enhance Kingston's local public transportation system. The multifaceted benefits include improving student safety, reducing the environmental impact caused by automotive emissions, and generating a profit. This approach strikes a perfect balance between people, profit, and planet, aligning with the triple bottom line – an indication of a successful engineering project. The achievements of this project are particularly noteworthy as they have the potential to revolutionize transportation systems not only for university students but also for larger communities.

Furthermore, the projects emphasis on sustainability, safety, and economic viability addresses key societal concerns. By lessening the environmental impact and enhancing safety, the team has demonstrated a commitment to well-being of both individuals and communities. The profitability aspect ensures the projects long-term sustainability and scalability, positioning it as a model for future endeavours in the realm of optimized transportation systems.

In conclusion, the teams' accomplishments go beyond the technical success of the optimized shuttle system, they represent a transformative initiative that embodies engineering design with social and environmental considerations. This project sets a foundation for future implementation, which will be discussed in the following section, Recommendations.

4. Recommendations

As the optimized shuttle service project advances, it is crucial to look ahead and outline recommendations that will enhance and grow the project, with a primary focus first, on expanding to other universities, and then potentially large corporations. The integration of Lloyd's algorithm and K-means clustering in the team's software has proven to be a robust solution for shuttle distribution based on population density maps. This section will delve into the strategic aspects of expanding the project and optimizing the software for broader applications.

4.1 University Expansion

The team's initial recommendation is to extend the shuttle system to other universities, creating a scalable model for success. This phased approach allows the team to monitor and assess how adaptable and effective the system is in different settings. By addressing the unique requirements of each university, the team can refine the software to ensure seamless integration.

Deploying the system in multiple university environments allows the team to validate its effectiveness across different campuses and student populations. This will require the team to adapt critical components of the software, such as the density map, and the velocity of the agents If applicable. Successful implementation in multiple universities would validate the software's efficacy stakeholders, future investors, and users, thereby growing its reputation for future adoption.

4.2 Commercialization

Once the software becomes a reputable product, proven to be effective and adaptable, the team will consider two routes: Collaborate with a tech giant or continue to enhance and develop the shuttle software in-house, creating a more well-rounded product for a global audience. For example, transportation companies for all cities could potentially utilize the application to allow pedestrians to track busses from their phone, with accuracy.

4.2.1 Collaborate with a Tech Giant

Exploring partnerships with tech giants, such as Apple or Google, offers a unique opportunity. The team's software, with its population density-based shuttle system, can be seamlessly integrated into Apples Maps app, or Googles, Google Maps. This collaboration allows these giants to elevate their mapping services and potentially allow them to partner with an existing shuttle service, such as Uber, or Lyft. This partnership would act in a similar manner to a bus line; however, it would operate based on population density metrics, rather than relying on a simple bus route. This would eliminate the problem of the busses being full upon arrival, as the places that need the most shuttles based on the density will receive them.

However, the downside to a tech giant partnership is the likelihood of a buyout rather than a 50/50 partnership. While providing strong financial upside, this would limit the team's ability to continue developing and enhancing the software. Despite this, it would still meet the projects objectives, though minimal involvement from team members.

4.2.2 In-House Development and Deployment

Should the team decide to continue to develop the shuttle service software in-house, there would need to be certain additions to the service. The current state of the project has the agents moving from a specified point on campus and distributing themselves based on densities. This is the correct end goal; however, the current routes the shuttles follow are all straight lines. This is completely unreasonable for a real-world application, as the shuttles would need to obey traffic laws and follow the road networks of the area the service is being deployed in. This could be demonstrated in MATLAB by using the road networks as a graph, assigning weights to the edges to set a boundary if necessary. By implementing Dijkstra's algorithm to determine the shortest path between points on the graph, the simulation would visually represent the identified shortest path across arbitrary time steps. The parameters of the graph can be adjusted to better fit real-world map data. This simulation would be imperative to the team's success moving forward, as the next step would be to partner with a shuttle company. The simulation would serve as a successful proof of concept that the team can use during discussions with potential partners and with marketing and advertising campaigns. The final step would be to create a maps service, similar to Maps, and Google Maps, but would be a niche product, only used by the partnered shuttle company.

Continuing in-house development would allow the team to shape the product as desired. However, it comes with associated risks, such as competing with well-established products like Apple Maps, Google Maps, Uber, and Lyft. This may pose challenges in finding investors and stakeholders, limiting funding and resources.

In conclusion, these recommendations aim to propel the teams optimized shuttle system forward by strategically expanding to universities, commercializing the software, or developing and deploying the software in-house. The phased approach ensures thorough evaluation and adaption, aligning with the projects objective’s and setting the stage for broader success.

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Appendix

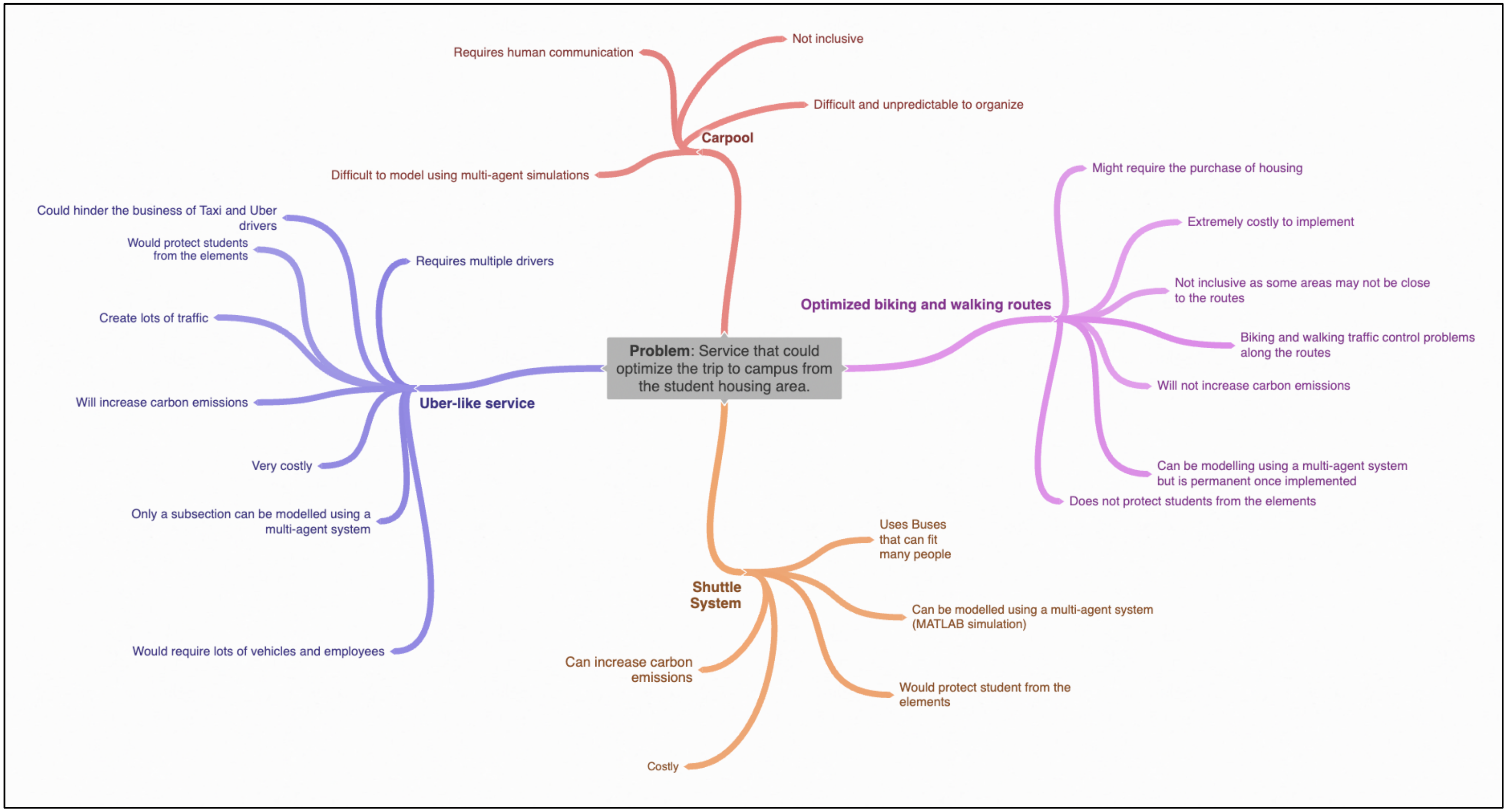

Figure 5: Above is a mind map used to brainstorm a broad range of potential solutions for an optimized transportation service [20].

Table 4: Below is a rubric that displays the difference between a score of 1 and a score of 5 for the potential transportation design solutions weighted evaluation matrix. Each specific design criteria is referenced and quantifiable examples are provided in each section so appropriate scores could be assigned.

Criteria	Score of 1	Score of 2	Score of 3	Score of 4	Score of 5	Weight (%)
Inclusivity	The potential transportation solution is not inclusive to anyone except people willing to pay a large amount of money. For example, a personal limo service.	The potential transportation solution is inclusive to only students and staff that know someone that owns a car. For example, a small carpool ring.	The potential transportation solution is inclusive to only students and staff that live near a certain area. **Such as a carpool service that uses a finite amount of drop-off/pick-up zones**.	The potential transportation solution is inclusive to only students and staff at Queen's University. **For example, a shuttle system/Uber-like service only for students and staff at Queen's University.**	The potential transportation solution is inclusive to everyone around campus along with the general public**. For example, a public walking/biking route or Kingston Transit.**	25
Effectiveness	The potential transportation design does not complete any of the functional requirements and is incomplete and not functional. For example, a broken down single school bus service.	The potential transportation design optimizes a student route to get to and from campus, but does not provide a transporting service**.** **For example, an optimized biking/walking route.**	The potential transportation design can only transport a small amount of students. **For example, a carpool service as only a few students would be able to fit per vehicle and the pick-off/drop-off zones will have a maximum capacity.**	The potential transportation design can transport a large amount of students, but can increase traffic, and provide long wait times. **For example, an Uber-like service with multiple vehicles because traffic would increase and long wait times could be evident.**	The potential transportation design can transport a large amount of students and staff, with short wait times, while limiting traffic. **For example, a properly scheduled shuttle system that operates around campus.**	25

Effectively Modelled using a Multi-Agent System	The design cannot be modelled using a multi-agent system. For example, the system has only one main component.	The design can be modelled using a multi-agent system but it is not effective. **For example, a carpool system because only the route from the pickup/drop-off point can be modelled, which could also be optimized using Google Map, making it not effective.**	The design can be effectively modelled using a multi-agent system, but the modelling may not prove effective to optimize design. **For example,** an **optimized bike/walking route can be modelled using a multi-agent system, but it may create too many paths, which would change over time, resulting in the unrealistic and ineffective construction of new pathways each year.**	The design can be effectively modelled using a multi-agent system but cannot be simulated using either the Consensus or Lloyd's algorithms**. For example, an Uber-Like service that has multiple different routes every day. This service will be hard to model using one of the above algorithms as the routes are always changing and the agents communication would require an additional algorithm.**	The design can be effectively modelled using a multi-agent system and can be simulated using either the Consensus or Lloyd's algorithms. **For example, a shuttle service that carries passengers on fixed routes which are determined by the density of students in the given area.**	50

SCAMPER Template: Referencing Kingston Transit

Substitute **S**	**What could replace what's there to improve it?** Use different elements as substitute for what currently exists.	• Substitute traditional bus routes with smaller, more agile shuttles to navigate through narrow or congested routes efficiently. • Substitute traditional fixed-route schedules with a route system that changes yearly based on the density of citizens in multiple areas.
Combine **C**	**Could it be made part of a bigger solution?** Combine or bundle what exists with other elements or components to create something better.	• Combine shuttle services with existing transit routes to create a seamless and comprehensive public transportation network. • Combine shuttle services with universities to establish a mutually beneficial partnership, where the university would financially contribute to the transit system, and, in return, their students and staff would have discounted shuttle fees.
Adapt **A**	**What can be modified and used in a different way?** Alter or change its function.	• Adapt shuttle schedules to cater to specific peak hours or areas with high demand, providing a more responsive and tailored service. • Adapt shuttle routes dynamically based on real-time data, incorporating feedback from passengers and adjusting services to address changing commuting patterns.
Modify **M**	**What happens if you change its size, shape, tone, frequency, etc.?** Modify what exists in its overall scale and scope.	• Modify the shuttle design to be environmentally friendly, considering electric or hybrid vehicles to reduce the carbon footprint. • Modify the payment system to streamline fare collection, possibly implementing contactless payment methods or digital passes for a more convenient and efficient experience.
Put to Another Use **P**	**What else can it be used for?** Use what exists as something for which it wasn't originally intended.	• Explore using shuttle services for community outreach programs, such as connecting residents to key facilities like hospitals, schools, and shopping centers. • Consider using shuttle services as a pilot for innovative transit solutions, incorporating smart city features like Wi-Fi connectivity, digital displays, or green infrastructure.
Eliminate **E**	**What can be removed that improves things?** Eliminate features or attributes in ways that make it simpler.	• Identify and eliminate underutilized or redundant bus routes, reallocating resources to strengthen the shuttle services in areas with higher demand. • Identify low-traffic or redundant bus stops and eliminate them in favor of optimized shuttle routes to reduce travel time.
Reverse **R**	**How can you move thing around to add value or create improvements?** Reverse the order of things or put things in different sequence.	• Identify and eliminate underutilized or redundant bus routes, reallocating resources to strengthen the shuttle services in areas with higher demand. • Introduce shuttle services that operate in a circular or loop pattern, providing residents with convenient access to various destinations within a neighborhood.

Figure 6: Above is a filled out SCAMPER template that references the Kingston Transit bus service and how it can be improved upon. This template was referenced during many design decision made throughout the project [13].

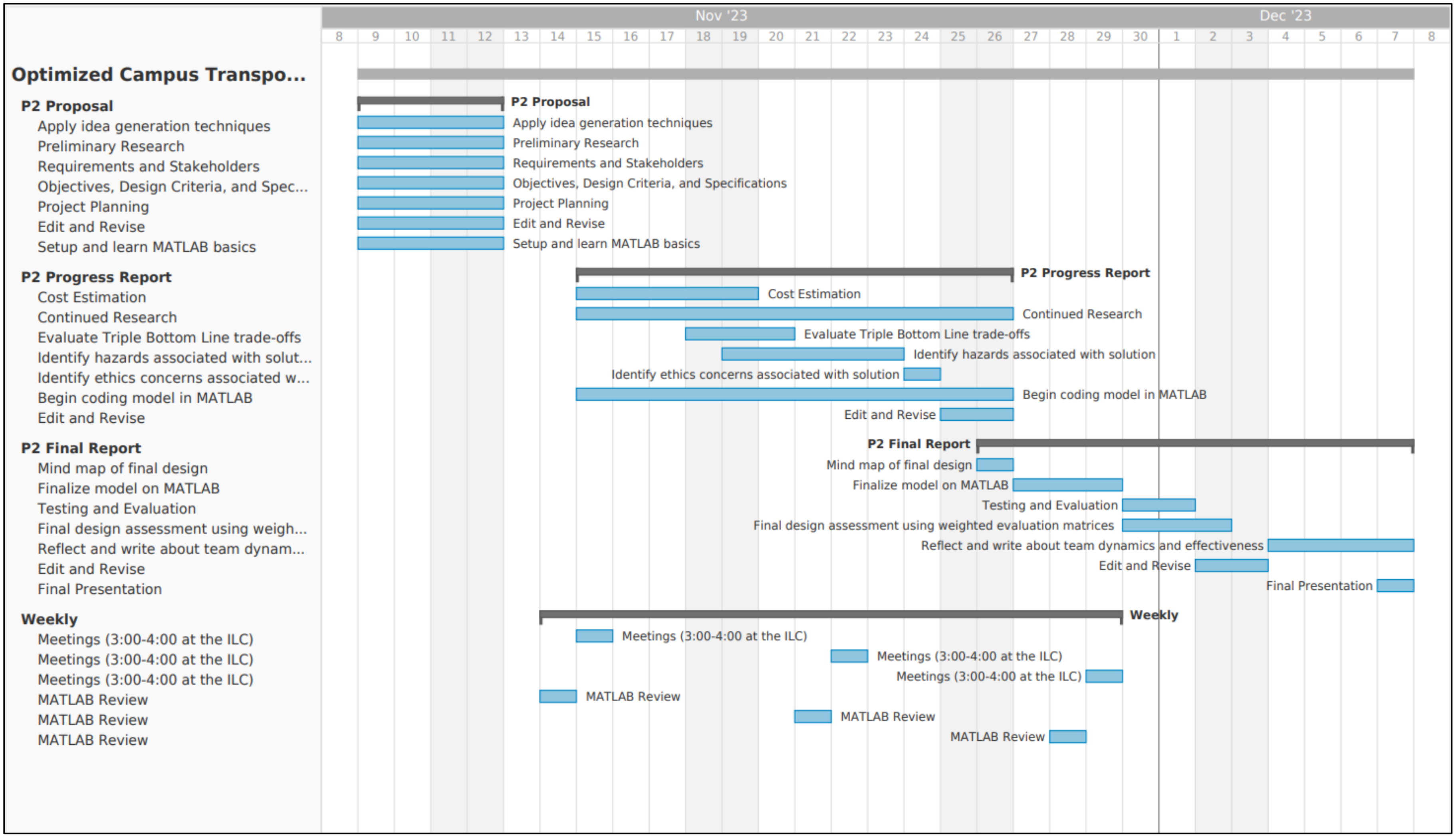

Figure 7 7: Gantt Chart - Project Plan.