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PLANNING AND DESIGN OF A SHARED CONNECTED AUTONOMOUS VEHICLE SHUTTLE BETWEEN A LIGHT RAIL TRANSIT STATION AND A MAJOR MEDICAL CAMPUS

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Abstract: The technology of connected autonomous vehicle has progressed well and shared autonomous vehicles (SAVs) are undergoing real-world demonstrations around the world. The SAVs can serve a number of market niches including first-mile/last-mile shuttle services. There are many potential benefits to travelers and society such as reducing the need to own a vehicle, increasing accessibility through on-demand service, or reducing emissions and maintenance with electric vehicles. `There are challenges associated with electrification, including the need for battery charging and development of battery charging infrastructure. The shuttle system will operate over several road types, including bus-only transitways, major arterials, collectors, and local roads. This system serves as an example of a first / last-mile service connecting The Hospital to the future Light Rail Transit (LRT) station at Hurdman. This paper covers the planning and design of a SAV shuttle system that will link the Smyth Road Medical Campus with the Hurdman LRT station in Ottawa (a distance of about 5 km). The paper consists of five parts. The first part serves as a background to the technology and service characteristics of SAVs. The second part defines the current system in place, and the problems associated with it. The third part describes the design of a new shuttle system using SAVs, including stations and battery charging facility. In the fourth part, benefits and possible further implementation scenarios involving LRT stations connected with SAV feeder shuttles are highlighted.

1 INTRODUCTION

Automated vehicle (AV) technology has been developing quickly in recent years. Soon AVs will become a safer and more reliable alternative to human-driven vehicles. However, AVs might not be the solution to traffic congestion that people are expecting. The convenience of autonomous vehicles may lead to a drastic increase in personal autonomous vehicle kilometres travelled (VKT) through increased solo ridership and the ability to have cars circulate in the system to avoid expensive downtown parking fees. The increase in the private autonomous vehicle VKT will disrupt the current mode share between personal vehicles and public transit. Furthermore, the higher VKT will lead to significantly higher road volume demands which cannot easily be met, even with AV technology. Public transit will remain the most efficient way to transport people in major developed cities in the foreseeable future (Walker 2018). With the advent of AVs on the horizon, the development and implementation of efficient and effective public transportation is more important than ever. Public transportation networks are often only suited to service the “middle” of the rider’s journey, as transit vehicles are usually unable to drive directly to each passenger’s origin or destination. This issue is known as the first-mile/last-mile problem, and it is often considered as the most challenging problem to develop public transit further and increase its mode (King 2016). The loss in ridership to other more direct modes has already been observed with the introduction of ridesharing services, which can provide more convenient, direct, on-demand services albeit at a higher price (Darrow 2017). These losses could increase and might eventually take over suburban and rural transit ridership if the city does not provide suitable strategies to counter the losses. The introduction of SAVs provides potential alternatives for the city to explore. This paper will focus on converting an existing public transit route in Ottawa between a major transit hub and a relatively isolated General Hospital campus as a pilot project to test out the design challenges and benefits of SAV systems. While this paper is primarily focused on a particular use case, this system could easily be applied to many other situations.

2 THE EXISTING SYSTEM

The Hurdman-Hospital Shuttle System will take feeder traffic from Confederation line and bus transit through the major hub at Hurdman Station. Hurdman Station is one of 13 stations on Ottawa’s nearly-complete Confederation line. This Light Rail Transit (LRT) line will run from Blair road in the east, through the downtown core, and to the Tunney’s Pasture government complex in the west. In future years, the line will be extended to the suburb of Orleans in the east, and Moodie Drive in the west.

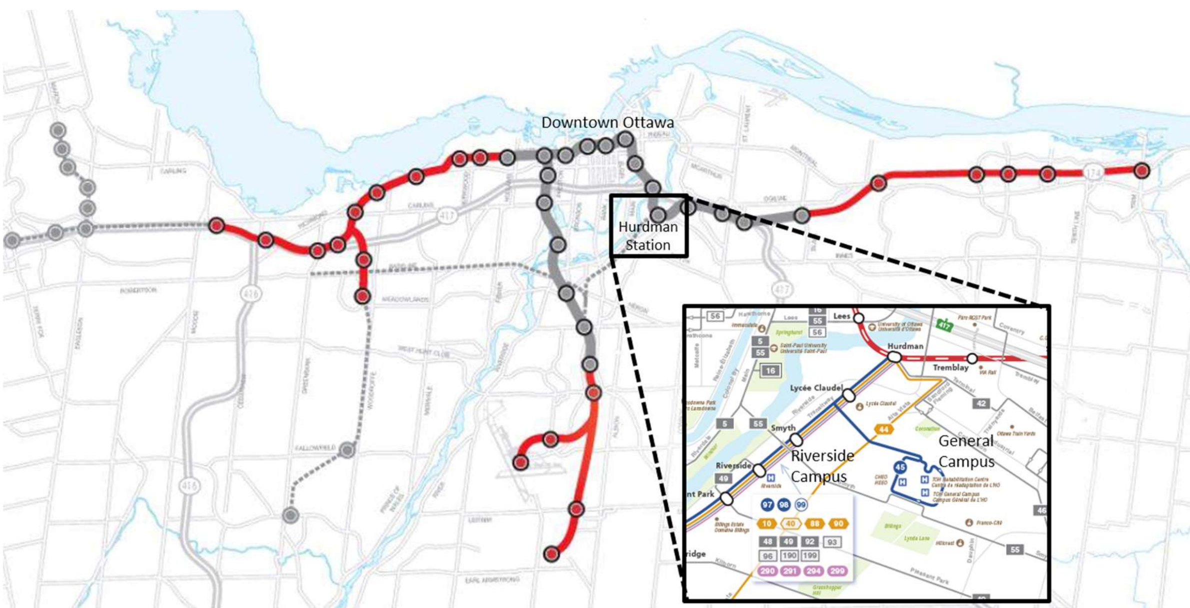

Figure 1 2031 LRT Map, Hospital area inset (OC Transpo 2018), (Infrastructure Canada 2017)

Hurdman serves as a major transfer point for 23 bus routes which primarily serve the southeast neighborhoods of the city (OC Transpo 2018). Several residential towers are also within a 5-minute walk of the station. The General Hospital Campus consists of the General Hospital Building with separate entrances for the Cancer Centre and Rehabilitation Centre wings, the Health Sciences Centre which houses the Faculty of Medicine for the local university, and the Children’s Hospital building. The buildings are enclosed by a Ring Road, with branches from this road leading to each entrance. The campus is connected to the rest of the city with two regularly scheduled bus routes. Route 45 is the primary hospital connector, running 6:00 AM to 12:00 AM between Hurdman and the hospital campus on a 15-minute frequency during the day, with half-hourly service on evenings and weekends and hourly service overnight (OC Transpo 2018) . Two buses with one operator each are dedicated to running this route throughout the day. The hospital is also served by route 106, which runs 5:00 AM to 1:30 AM at 15-minute frequencies and only enters the campus when travelling west. The route only travels along the south edge of the campus, despite it being the only line to directly serve the smaller Riverside Hospital Campus, 1.3 kilometres to the east. In the next year, Route 106 will be combined with another route which will effectively sever the direct link between the General and Riverside Campuses (OC Transpo 2018). The primary vehicle used on these routes is the standard 40ft bus which has a capacity of up to 41 seats, or 35 seats and 2 wheelchairs (OC Transpo 2018).

2.1 Challenges of Current System

There are several challenges of the current system, which limit its current effectiveness. On route 45, there are potentially long wait times during off-peak hours, with a reduction to 1 bus per hour during the night. On weekends, service is limited to 30 minutes between buses all day, with hourly overnight service (OC Transpo 2018). This lack of frequency is a significant barrier to transit for many of the hospital employees due to their unconventional working hours. Due to route 106's lack of access to the campus when travelling eastbound, there is a walk of at least 250 metres for those who wish to travel from the Riverside Hospital to the General Hospital. This poses a barrier to those moving between campuses, particularly in the winter when sidewalks can become difficult to walk on. Although both routes do have some ridership, it is not uncommon for buses to carry loads of 10 passengers or less, despite having seats for 41 and plenty of standing space. Conversely, some buses during rush hour usually have all the seats filled, with additional standees. This reduces rider comfort and the comfort level will eventually deteriorate with population growth and additional demand if nothing is done.

As a result of insufficient public transit services connecting the General Hospital Campus to Hurdman and between General Hospital Campus and Riverside Hospital Campus, many employees and patients choose to drive to the Hospital which results in increased congestion and limited available parking. As the city's population grows and ages, more demand will be placed on the hospital systems, requiring further expansion of parking unless transit can improve and provide a more attractive service. The introduction of the LRT will help with this, resulting in a subsequent increase in demand on the hospital route. Increasing service and convenience will result in an even greater modal shift. However, increasing service requires more bus operators and would only result in a limited decrease in wait times during the day, and the limited number of travellers at night would likely result in high operating costs relative to the number of passengers served. Thus, the current system cannot be expanded without incurring significant operating costs for limited benefit.

3 PROPOSED SYSTEM

The proposed system would be able to completely replace Route 45 and partially replace the function of route 106. The system will be described in the following categories: Operation protocols of the system, Design specifications for vehicles, Design of stations, and Design of charging stations. Additional safety and accessibility features will also be discussed.

3.1 Assumptions

There are currently many technological advances and developments underway with the development and production of Shared Autonomous Vehicles and SAV infrastructure. For this reason, 4 critical assumptions are made as follows:

1. SAVs will be capable of operating seamlessly on roadways shared with private vehicles.
2. SAVs will be able to operate year-round, maintaining acceptable battery life in cold weather as well as maintaining traction, control, and communications in snow, ice, fog, and rain.
3. Communication will be sufficiently capable between SAVs, the network and other city services, to allow for pre-emptive traffic signalling reducing travel time of shuttles, and to provide adequate notification of approaching emergency vehicles so the SAV can respond accordingly.
4. Through the combination of law enforcement, vehicle regulation, and infrastructure design, SAVs should be capable of navigating through any ethical dilemmas under legal operation.

The above statements are assumed to be correct by the time of implementation.

3.2 Operation, Scheduling and Routing

Autonomous shuttles can operate on both a fixed route service, as well as an on-demand shuttle service. The schedule for this shuttle service has been divided into 2 main modes of operation to optimize use and to accommodate and the ridership demand; fixed routing and on-demand service. During daytime travel, the demand from Hurdman Station to the General Hospital Campus is predicted to be high, requiring a fixed routing and frequency. However, demand from the General Hospital Campus to the Riverside Campus and the overnight period, the predicted demand is quite low, allowing the system to be tailored to on-demand service. The daytime routing for this service is demonstrated in the figure below.

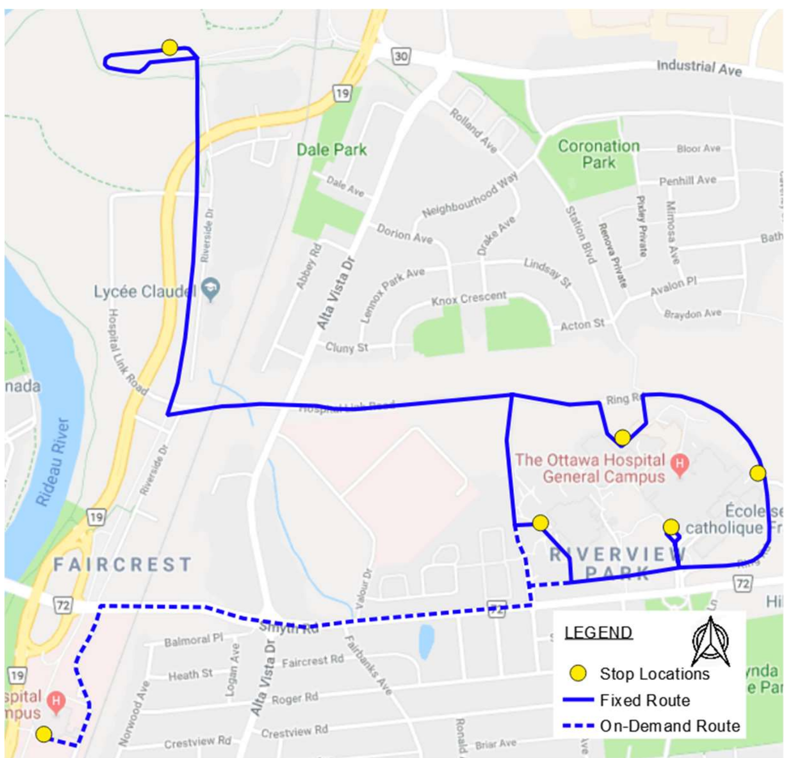

Figure 2 Map of the route and daytime service levels

By analyzing Automatic Passenger Count (APC) data from the existing route, a ridership profile can be determined. Using the Regional Transportation Model data from the municipality and growth factors, future volumes can be predicted. The future volumes can then be overlaid onto the ridership profile, determining the number of shuttles required during different time periods. Based on the ridership, during the day the shuttle will run on three frequency settings, peak, mid, and low demand. The frequency for these systems will be 2.5, 3, and 5 minutes respectively. This ensures an easy-to-use system through the day.

The three fixed routing frequency and the on-demand options are intended to reduce the VKT. In addition to these options this shuttle service will be able to operate dynamically. The dispatcher will be able to monitor crowding and deploy additional vehicles when needed. In the future and when volume exceeds the capacity that can be provided by single shuttles, the system will have the ability to use platooning technology, virtually linking the shuttles together to form a longer multi-unit 'train'. This will allow the capacity to be increased effectively without significantly increasing the required road space and traffic volume.

3.3 Vehicle Design

Significantly lower occupancy shuttles were selected for this system when compared to standard bus sizes. The benefit of this is the smaller size and turning radius, which can accommodate drop-off and pickup locations that a standard bus cannot service. The smaller vehicles also allow for more efficient asset use when shuttles are not at capacity. Overhead chargers will be used for this service; therefore, the shuttles must be equipped with connecting hardware.

A design vehicle must be chosen such that dimensions and capacity are known and stations may be designed around it. The vehicle chosen for the system was commercially available and has room for 15 passengers, with 11 seated and 4 standing. Three seats will fold up to allow space for a single wheelchair. The shuttle has a length of 4.75 m, a width of 2.11m, height of 2.65 m and a ground clearance of 0.2 m (Navya 2018).

Figure 3 Example of a Shared Autonomous Vehicle

The chosen vehicle features all-wheel steering and a turning radius of just 4.5 metres. It was also assumed that, much like other all-wheel steering cars, the front and rear axles are independent of each other. This unique vehicle's capabilities are not easily represented by TAC's templates, so a new design vehicle was created. Three turning templates were designed to represent the turning path under different axle configurations. This was later used in station design to minimize the required space.

3.4 Station Design

Stations used in this system will be categorized into two types; Hub Stations, and Curbside Stops. The system will have a total of 3 Hubs and 3 Curbside Stops.

3.4.1 Curbside Stops

Curbside stops are minor stops along the route with low passenger volumes, akin to a bus stop. Benches or small shelters may be available, as will a single kiosk which will allow passengers to hail a shuttle during on-demand periods. These kiosks are further described in section 3.4.4. Where space is available, curbside stops will also be raised to the shuttle's floor height to facilitate boarding. Curbside stops can serve up to 2 shuttles at once.

3.4.2 Hub Stations

Hub Stations are used as major transfer points where high passenger volumes and transfers between vehicles are predicted. These stations feature raised platforms in line with the shuttle's floor height to increase accessibility and eliminate stop dwell times caused by the deployment of the wheelchair ramp. The stations will be a fully enclosed, lit, heated structures capable of serving a minimum of 2 vehicles and most commonly designed for 3. Platform Screen Doors will ensure that passengers are kept out of the roadway and do not interfere with shuttle operations. Passenger information screens above the Platform Screen Doors will indicate when the next shuttle will depart, and which door to wait at. Benches will be provided for passengers to sit and wait, although the wait time is not expected to be long. The platform screen doors are positioned to allow a shuttle to overtake another shuttle waiting at the door ahead of it.

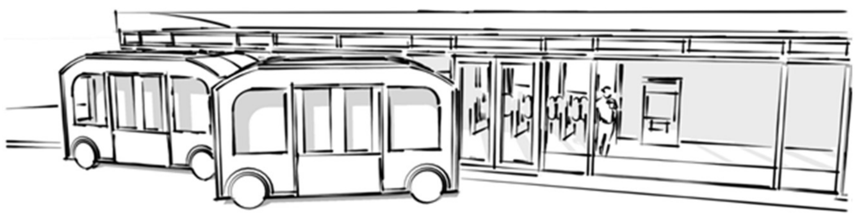

Figure 4 Sketch Rendering of a Hub Station

3.4.3 Testing and Validation of Hurdman Station

Hurdman Station will be the largest and busiest station on the network, and as such is large enough to accommodate the maximum passenger volumes of the system. Hurdman is also the only station where fares will be collected, thus faregates will also be installed. Passengers leaving the shuttle system will pass through these gates and enter the fare-paid zone of Hurdman Station's bus loop. Passengers will be able to walk directly to another bus or up to the LRT platforms without having to pass through any additional gates. Oasys MassMotion was used to validate the Hub for passenger flow. It was found that the station could handle simultaneous boarding and alighting from all 3 doors, for a maximum passenger flow of 1080 people per hour per direction. This means the station should easily accommodate the predicted peak passenger volume of 246 people per hour per direction with ample space for future growth and expansion.

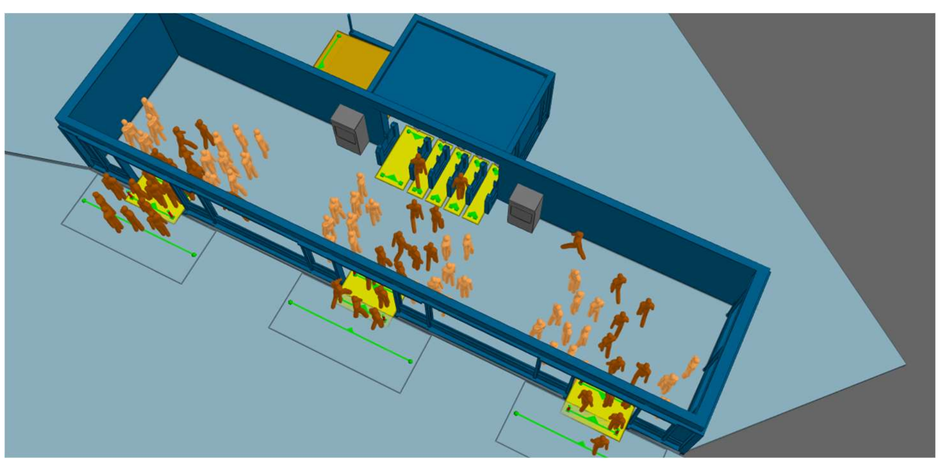

Figure 5 Analysis of (Newell 2015)Hurdman Station in Pedestrian Simulation Software

3.4.4 Kiosks

Kiosks will be installed at each transit stop along the shuttle route to help passengers navigate and hail a shuttle during on-demand periods. The kiosk will follow universal accessibility principles such that it can be utilized by everyone regardless of ability or disability. Each kiosk will be constructed such that it can withstand Ottawa's seasonal climate (-40C to +40C), (WeatherStats.ca 2019) is waterproof, and capable of being powered by solar panels. The kiosks will include written language and audio output in both English and French, with the ability to include additional languages in the future. The interface will display maps, route options and include tactile buttons with destination listed in English, French and braille. The kiosk is designed such that the height of the screen and buttons are in accordance with AODA standards. (Newell 2015) Electrical infrastructure will be required to power the kiosk in the event that the solar panels produce insufficient charge. A concept of the kiosk interface is provided below.

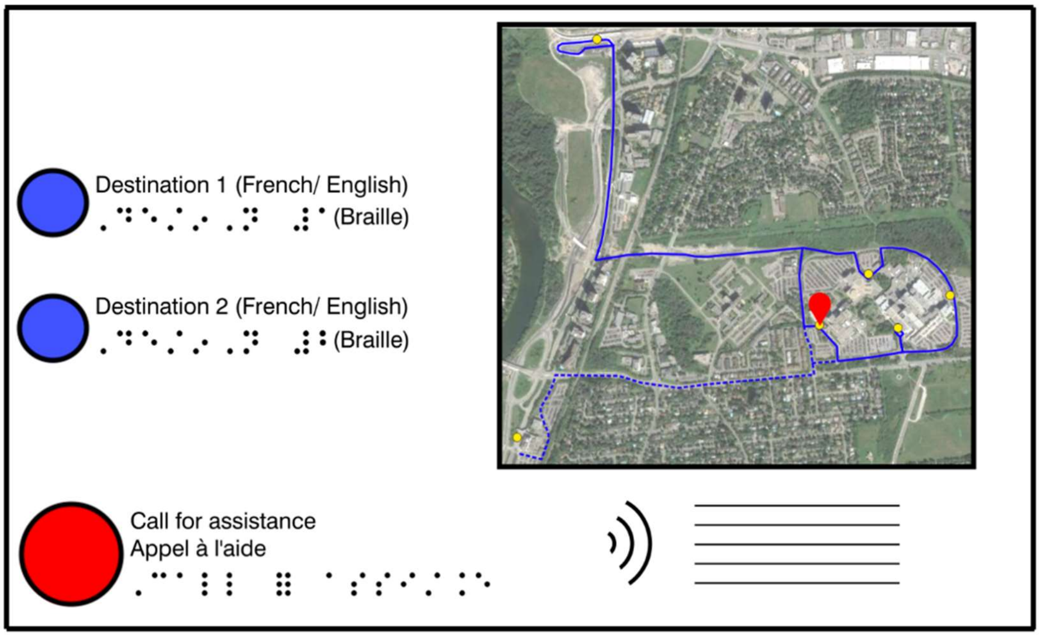

Figure 6 Kiosk General Interface

3.4.5 Revenue generation

The system will operate in cooperation with and as a part of the local transit network. Fare integration will be in place, allowing shuttle users to board buses and light rail trains without paying a second fare, and vice versa. The shuttles do not have a fare collection system on board, as would it not be easy or practical to enforce fare payment on the vehicle. Instead, fares will be collected at Hurdman Station using faregates. The design of the faregates will be consistent with current fare gate designs and one gate will be capable of accommodating wheelchair users in compliance with the AODA. (Newell 2015) Fares will only be collected at Hurdman, which is predicted to be the connecting station with the highest passenger volume. Ticketing machines will be required to allow passengers paying with cash to exit the system. These will be identical to the fare machines that are currently in use by the local transit company. Advertisements in the Hub Stations or on the vehicles can also provide some income to help offset operating costs. These advertisements will be consistent with the transit company's current advertising standards. The goal of the project is not to turn a profit; Rather, it is to reduce the operating subsidy and increase both ridership and capacity. Funding and operating subsidies from the hospitals, city, and transit authority will fund the remaining costs if any exist.

3.5 Charging Station Design

The current system design utilizes four overhead charging units located at Riverside Hospital, the Children's Hospital, and Hurdman Station. There will be one at each charging site except for Hurdman, which will have two. DC fast chargers will be used which can deliver power up to 450 kW and will be made compatible with the shuttle's battery system. This system is currently in use charging standard 40ft electric buses in many cities including Montreal. (Laanela 2018) Chargers will be situated next to the roadway such that a shuttle can position itself under the charger and then remain there until fully charged.

Overhead chargers will be cantilevered out over the shuttles with enough height to accept shuttles and buses ranging from 2.5 m to 3.5 m. The charging station will be equipped with a pantograph connection that will lower to the roof of the shuttle and contact the charging port.

3.6 Safety Features

In order to satisfy passenger demand and provide a safe and comfortable experience to all passengers, the shuttle will include the following features; automated stop and information announcements, climate control, automated doors with manual override, distress buttons, window-breaking devices, fire extinguishers, emergency exits through the roof or windows, and GPS tracking to communicate with the overall network to estimate arrival or departure times.

To further increase safety and reduce liability, CCTV cameras will be installed at all stations and on shuttles both inside and outside of the vehicle. Surveillance feeds will be continuously monitored by a dispatcher in the central control room who will make announcements, reroute shuttles, or take control of the shuttle remotely if required. In the event of a detected collision the shuttle will automatically save and timestamp all recorded video feeds for further review. Aside from flagged footage, video will be stored for two months prior to deletion.

3.7 Accessibility

Due to the nature of this system serving as a hospital shuttle, emphasis on accessibility is even more important. As such all design choices are made in accordance with AODA standards. In order to accommodate passengers of all abilities, the following features have been included in the shuttle; a deployable ramp wide enough for wheelchairs or strollers, stop announcements both visually and audibly in English and French, courtesy seating with retractable seats for passengers with mobility issues or strollers, easily legible visual signage, and sufficient handrails.

Each shelter has been designed with accessibility in mind and will include the following features; raised concrete pads level with the shuttle floor, ramps with a slope no more than 2%, easily legible and consistent visual signage, obstruction free loading areas, sufficiently wide entrances, wide automatic platform screen doors, and Tactile Walking Surface Indicators leading up to shelters and at platform edges. (Newell 2015)

4 BENEFITS

4.1 Convenience

Implementation of the new service will result many benefits including an increase in convenience and a decrease in wait times. Through the application of an on-demand service during off-peak hours, the system increases accessibility and convenience without significantly raising costs. The convenience of the service is expanded further through decreasing the headway and waiting times from 15 minutes to less than 3 minutes during rush hours to accommodate the demand while retaining capacity. Kiosks will be available at each stop to help serve passengers, where customers are able to receive navigation assistance and request shuttles during on-demand periods.

4.2 Modal Shift

Modal Choice was examined according to the City of Ottawa's long-range transportation demand projection model. In 2011, the modal split between auto and transit to General Hospital area as a destination was 78% and 21% respectively, whereas in 2031, the same modal split is predicted to be 77% and 22% respectively. However, the Transportation Master Plan of the City stated that by the year 2031, transit mode share citywide will be increased from 22% in 2011 to 26% in 2031, an increase of 4% (City of Ottawa 2013). According to the model, the transit modal share in the hospital area increases 1%. This implies that despite a direct bus connection, ridership growth using a fixed route without changes would be below-average. A more efficient and convenient service may result in a larger increase in ridership, representing a stronger shift in modal share and higher ridership for the transit system as a whole.

4.3 Efficiency of service

The system design is intended to increase operating efficiency as well as reduce lifecycle costs. The operating costs of the system can be reduced through the use of Autonomous Vehicles, while improving frequency. System efficiency will be increased through optimal routing, acceleration and braking, and use of fast-charging technology. Services can be increased or decreased to directly respond to demand without incurring the additional costs of an operator. Low-demand and overnight services can be run precisely when there are passengers, and only rarely when no demand exists.

4.4 Environmental impact

This project aims to increase efficiency of transit system between Hurdman and the Hospital Campus while reducing environmental impacts. The new service will use electric vehicle technology, and stations will use solar panels as a supplemental energy source. This reduces the environmental impact through the reduction of energy consumption and the elimination of tailpipe carbon emissions.

5 IMPLICATIONS FOR FUTURE DEVELOPMENT

The implementation and design of this shuttle system opens the door to further uses as a feeder system, particularly in suburban areas where transit service is poor. Suburban areas are generally very difficult to serve using traditional bus routes, with meandering lines, poor frequency, and low ridership. Paratransit and dial-a-bus services have been trialled in the past, but the high associated costs and low frequencies have led to the cancellation of many of theses services. Currently, many suburbs are limited to low-frequency local routes and rush hour commuter links.

The proposed system can help fill this gap using hub stations and a network of local curbside stops, providing the convenience of dial-a-bus services without the high costs and lower frequencies. Combining the Hub Stations with higher-order transit such as Bus Rapid Transit, Light Rail, Heavy Rail, or Commuter Rail, the system can provide a solution to the first/last mile problem, directly linking passengers to their destinations. This would provide a valid alternative to private vehicles, with the ability to pick up multiple passengers on the way to a common hub. By doing so, pressure on adjacent park and ride lots can be relieved. This would also be an ideal replacement for fixed-route suburban services with lower operating costs and higher frequencies. When combined with Transit Oriented Development at Hub Stations, feeder shuttle systems can also be used for grocery runs, shopping trips, and other non-commuting uses.

CONCLUSION

The development of Shared Autonomous Vehicles opens up vast application opportunities to explore. Cities can take advantage of this technology and employ it in the public transit sector to increase transit modal shares and reduce the number of private vehicle miles travelled. This system demonstrates one such application of SAV technology as a combined feeder service and campus circulator, offering higher frequencies, capacities, and demand-response capabilities for lower operating costs than a conventional bus system. Through systems like these, cities and transit organizations can unlock the potential of Shared Autonomous Vehicles and observe their benefits.

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