ATTACHMENT 1

Source: Sidewalk Labs

Achieving Integrated Mobility in Saskatoon

A Review of Intelligent Transportation System (ITS) and Emerging Mobility Models

Bus Rapid and Conventional Transit Planning and Design Services

City of Saskatoon

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Contents

1 Introduction

As the City of Saskatoon continues to grow and urbanize, one of its primary goals is to build an increasingly sustainable community over time. If existing trends continue, vehicle trips are expected to increase by 220% and travel times could increase by up to 300%. To mitigate these issues, the City's *Growth Plan to Half a Million* has identified two strategic goals:

- To ensure balance growth between old and new neighbourhoods; and
- To improve city-wide connectivity by providing alternate travel modes to the automobile.

To meet these goals, the City's BRT / Transit Plan initiative will increase the transit system's speed and efficiency, support growth intensification, and set the stage for the City to consider complementary innovations in technology and mobility. This report provides an overview of these innovations, their relevance, and their potential to support the City's strategic goals.

1.1 The Urbanization Context

Over the past century, Saskatchewan has become increasingly urban. At the turn of the 20th century, only 16% of Saskatchewan's population was classified as urban, as shown in **Figure 1**. A century later, almost two-thirds of the province's population was urban, and that proportion is expected to continue to increase. The trends in Saskatchewan are reflective of those around the world. According to the United Nations, in 2014 about 54% of the world's population was urban; up from 30% in 1950. By 2050, 66% of the world's population is projected to be urban[1].

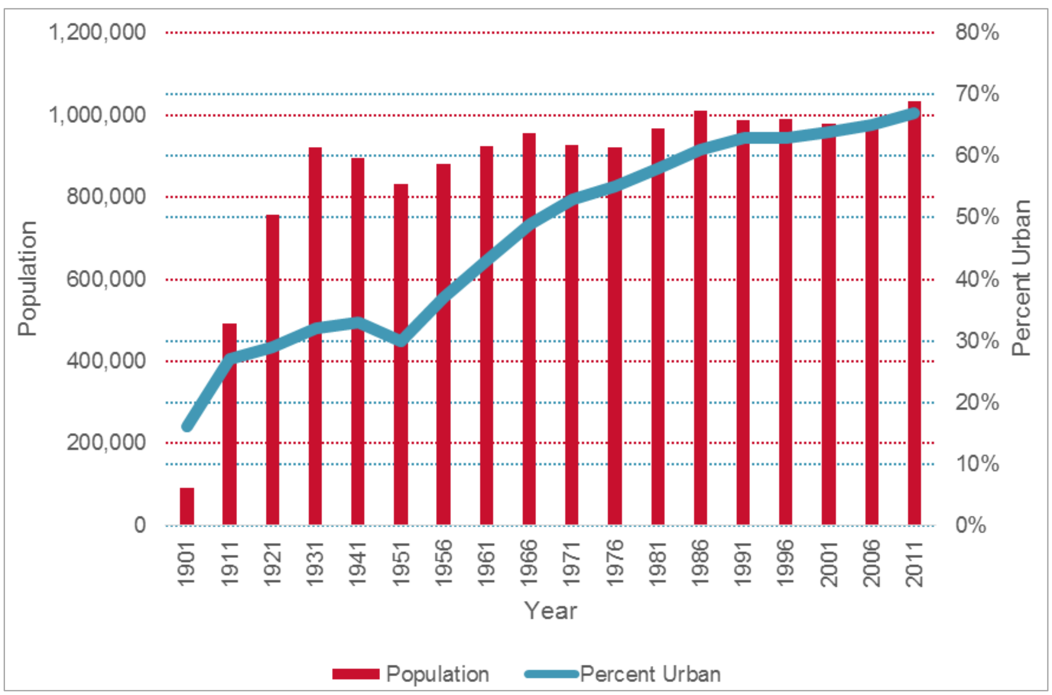

Figure 1: Population Growth and Urbanization in Saskatchewan[2]

[1] World Urbanization Prospects, 2014 Update. United Nations. 2014
[2] Statistics Canada

As Saskatchewan's largest population centre, Saskatoon will continue to play an important role in the urbanization of the province. The City's Growth Plan reflects this role and the increased pace of growth expected in the coming decades.

A more urban-focused community is one that has higher expectations around connectivity, shared resources and information than the urban centres of the past that grew out of a need to service the rural areas around them. Given that urbanization is a global trend, Saskatoon is not alone in facing the challenges and expectations of rapid urbanization.

1.2 The Smart City Context

Cities around the world are declaring their desire to become a "Smart City" as a means to meet the demands of urbanization, but many don't truly understand what being a smart city means. The focus is too often solely on technology or another single element of city services or infrastructure. *Frost and Sullivan*[3] identified eight key attributes of a smart city, and define a smart city as one that is built on solutions and technology that will lead to adoption of at least five of the eight attributes illustrated in **Figure 2**.

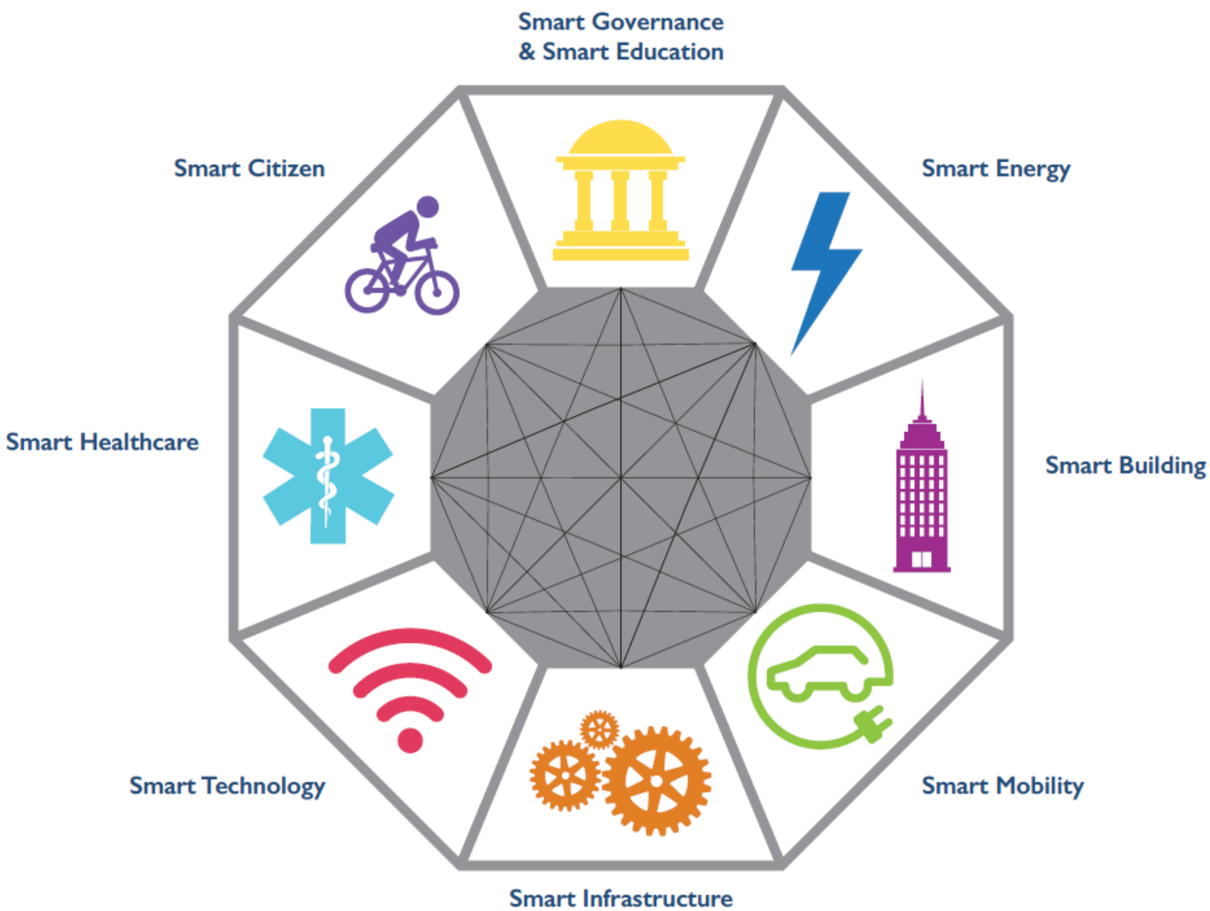

Figure 2: Smart City Key Attributes [3]

[3] Frost and Sullivan, Smart Cities Need Telecommunications Service Providers: Smarter solutions provide opportunities to manage resources, create better quality of life. 2016

Smart cities are about people, not technology. Technology is an enabler, but ultimately being "smart" is about understanding and managing the interactions between citizens, infrastructure and services, and city government.

For cities like Saskatoon, one of the first steps in the evolution to becoming a smart city is breaking down internal silos and barriers between city departments. It is impossible to ultimately create an environment where information and data are widely shared and used in the public domain if information and data isn't widely shared and used within the City organization. Saskatoon has made some steps toward creating open data, such as the availability of transit data to privately-developed smartphone apps. However, there is a need for a much broader view of how to make city data open and available to all before there can be any serious discussion about Saskatoon becoming a smart city.

The Smart Cities Readiness Guide[4] identifies several barriers to smart cities implementation:

- Siloed, piecemeal implementations created by short-term financial constraints and siloed city departments with little interaction leading to unnecessary redundancies;
- Expectations for instant, anywhere, anytime, personalized access to city information and services;
- Lack of clarity and lack of communication about what being a smart city means;
- Unwillingness to explore new financing models, and reliance solely on tax revenue;
- Lack of Information and Communications Technology (ICT) skills in-house, combined with an unwillingness to partner with experienced service providers;
- Lack of integrated services based on applications that limit access rather than opening access to data and information; and
- No visionary leader to pull the parties together and create the change in attitude necessary to break down silos and develop an open data environment.

Not all of these barriers apply to Saskatoon, and as noted above, Saskatoon has taken steps to address some of the barriers.

1.3 The Integrated Mobility Context

The city of the future will be one where urban mobility is focused on providing a seamless experience for everyone in the community. Saskatoon has already identified some of the initial steps to implementing smarter mobility, with the introduction of BRT being one. Moving forward, there are several smart transportation applications that Saskatoon can explore, from cycling infrastructure to preparing for autonomous vehicles.

There are many titles given to mobility initiatives that support the evolution to a smart city. Integrated mobility is a commonly used term that can be defined as "The ability for people to move easily from place to place according to their own needs."[5] It is a people focused goal that:

[4] Smart Cities Council. Smart Cities Readiness Guide. https://rg.smartcitiescouncil.com/readiness-guide/article/introduction-introduction-smart-cities

- Starts with public transit connected to all modes of transport including walking, cycling, auto, and alternatives to transportation;
- Enables door-to-door and seamless mobility throughout an urban area; and
- Is designed for all segments of the population.

Integrated mobility recognizes that transit is about more than just transit. It requires an integrated approach to transit that considers all elements of a trip, by multiple modes delivered by multiple agencies – public or private.

There are many smart technology concepts and approaches being applied to urban mobility, which can help communities achieve their integrated mobility goals. The purpose of this memo is to explore these technological advancements and emerging mobility trends, and identify how they may impact Saskatoon Transit, including the Bus Rapid Transit (BRT) project.

The document provides a summary of key transit and other mobility applications. Mobility and demand management are discussed, along with opportunities to improve transit service and delivery through the adoption of emerging technologies and/or the exploration of new mobility trends. This includes but is not limited to ridesharing, autonomous vehicles, and alternative propulsion technologies. The applications have been grouped as follows:

- Intelligent Transportation Systems (ITS)
- Vehicle/Fuel Propulsion
- Emerging Technologies
- Mobility Hubs

The focus of the document is on transit within Saskatoon, but broader mobility and smart city considerations are discussed throughout, recognizing that integrated mobility requires an understanding of the interrelationships between all mobility modes and other facets of life in Saskatoon.

[5] Canadian Urban Transit Association, 2017, Integrated Mobility Implementation Toolbox
http://cutaactu.ca/report/mobility-management/images/CUTA_Integrated_Mobility_Toolbox_September2017_English.pdf

2 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) are defined as a technology that improves safety, operations, and maintenance of a transportation system, or provides enhanced information to the users of a transportation system. ITS applications for transit cover diverse categories including:

- Fare Collection – technologies that involve some form of electronic fare collection intended to allow for fast and/or cashless interface for fare payment
- Passenger Information – methods that allow passengers to make the most efficient use of their time by providing schedule and other information via smartphones, displays and other methods
- Transit Signal Priority – methods to provide preference or priority to buses in mixed traffic
- Intelligent Vehicle Initiatives (IVI) – application of connected vehicle techniques to provide a level of automated control over the transit vehicle to assist the operator
- Operations Management – technologies that enhance the operation of the fleet
- Data Collection and Monitoring –technologies ranging from automated data collection to video/voice monitoring at stations and on-board vehicles

2.1 Fare Collection

Description: Traditional cash-box fare collection allows passengers to pay with cash, tickets or other physical forms of payment. In many cases, traditional payment places a burden on the passenger to have exact change or some form of pre-paid payment such as tickets or a bus pass, and also causes delays because it typically requires front door boarding In addition, there are significant costs to the transit system to process cash and near-cash fares.

As society becomes increasingly cashless, the practicality of cash payment will become challenging. Transit operators globally have been undergoing changes in how fares are collected. Most still accept cash, tokens or tickets, but many are now offering alternatives that are more convenient for the passenger and reduce dwell times associated with payments while boarding. The following are some of the technologies that are now being used to collect fares.

- **Magnetic Strip Swipe Cards** – In the context of today's technology, swipe cards are a low technology solution. In many cases, swipe cards replaced strip tickets for use with electronic fare boxes. The advantage of swipe cards is their relatively low cost and reasonably fast processing on-board. They can easily be sold off-board via ticket vending machines. However, on-board or online sales are not practical, and the cards are easily prone to damage. Many transit systems are now beginning to phase out swipe cards.
- **Smart Cards ("Closed Loop" Systems)** - A smart card is a contactless, reusable, prepaid, pocket-sized card (usually the size of a bank card) that includes an embedded microchip to monitor fare transactions and stored balance. Smart cards are widely used and acknowledged as a secure and reliable transit fare payment system. In single zone systems, passengers tap their card upon boarding. In multi-zone systems, passenger

tap their card on entry, and again when leaving the bus. Various methods are available for reloading cards, such as topping-up a user account with a credit card via a website or through vending machines. While smart card systems bring numerous benefits to agencies and customers, some drawbacks remain. Implementation in many systems has been challenging. Smart cards implementation in Winnipeg and Vancouver were delayed for several years, with significant cost overruns, and Calgary eventually abandoned implementation. Many of these benefits and drawbacks are listed in **Table 1.**

Figure 3: Typical Transit Smart card reader King County, Washington[6]

Table 1: Advantages and Disadvantages of Smart Cards[7]

Advantages	Disadvantages
• Improved flexibility, customer service and ability to modify fare structures. • Improved revenue accountability and security by moving away from cash collection since revenue is settled electronically. • Reduced fare abuse—reduction in fraud and counterfeiting of paper fare products such as tickets. • More accurate and detailed ridership data eliminating the need to collect data manually. Automated collection of revenue and ridership information including riders from all ages and any station. • Reduced transit operator and rider interaction speeding up the fare collection process. • Flexibility for regional fare integration—allows use of single fare medium and appropriate equipment on multiple modes and agencies.	• Potential system failure/crashes can cause delays and inconvenience to customers. • Personal data security issues in the event that personal account information gets compromised. All transaction details, including the amount, time, and owner details are stored in a central database. • Issues with transferring funds from bank to smart card may limit usage. • Internet and telecommunication infrastructure are an integral part of the operation. A significant failure will affect transit operations. • High implementation cost – the Peggo card system in Winnipeg had an estimated cost of $17M

[6] https://www.everetttransit.org/163/ORCA
[7] Smart Card Alliance Transportation Council,2011, Transit and Contactless Open Payments: An Emerging Approach for Fare Collection

- **Credit Cards / ePurse ("Open Loop" Systems)** – Some transit systems, such as the UTA in Salt Lake City have started accepting contactless debit/credit cards using technologies such as Visa's payWave or Mastercard's Paypass. Unlike smart cards in which store value on the card, credit card fare payments are added to the cardholders' monthly statement along with other credit card purchases. In some cases, specific cards have been developed that expand the utility of the card beyond transit fare payment. For example, the Octopus Card in Hong Kong is a multiple use card that combines debit/credit functions as well as transit fare payment. Like other smart cards, value can be preloaded or topped-up through a website.
- **Smartphones** - There are two types of smartphone applications in use. One essentially uses the phone as a smart card, using Apple Pay and Android Pay technologies, such as in Chicago. The other method is a lower technology solution that essentially allows a user to purchase an electronic ticket which can be displayed to the driver upon boarding. The passenger would download an app to their phone, such as the Metro Transit app in Minneapolis/St. Paul, and purchase tickets through the app. Calgary is currently exploring a similar fare payment system.

Case Study: Octopus Card – Hong Kong: The Octopus Card, shown in **Figure 4**, is a smart card that was launched in Hong Kong for Metro Rail Transit (MRT) in 1997. This card allows service integration under one fare structure for six different transit agencies operating in the same city. The card users earn points over time and can redeem points at various stores and services. Moreover, the cards can be set to automatically reload once the balance drops below a set value. Over the years, the card's service has been extended to over 8,000 service providers, including:

- Buses, ferries, coaches, railways, tramways, taxis
- Retail (shops, supermarkets, and select restaurants)
- Car parks and on-street parking
- Photocopiers and vending machines
- Leisure facilities
- Access control to commercial and residential buildings
- Hospitals, schools, and public service fee payments

In 2014, Octopus was launched as a smartphone app to eliminate the need for a physical card. Payments were then processed through Near Field Communication (NFC) on enabled devices. According to Acorn Marketing & Research Consultants (International) Limited, approximately 99% of people in Hong Kong between the ages of 15 and 64 have an Octopus card[8].

[8] http://www.octopus.com.hk/get-your-octopus/where-can-i-use-it/en/index.html

Figure 4: Octopus Smart Card and payment receive systems

Applicability in Saskatoon: It is clear that the days of cash-only fares are coming to an end. Without some form of cashless payment option, attracting new customers that no longer carry cash (Millennials in particular as less likely to carry cash, and even less likely to have change than others) or carry limited cash will be difficult. There is a growing expectation that any purchase can be made without cash. However, Saskatoon should learn from the lessons of other cities. Smart cards are the most dominant form of cashless payment currently in use, but the implementation experiences in cities like Winnipeg, Calgary and Vancouver suggest that there should be significant caution applied before considering smart card implementation. Saskatoon may be better served by closely monitoring payment options via smartphones. In particular, the electronic ticketing app that is being considered in Calgary may offer a payment option that requires little implementation infrastructure. By focusing on smartphones for electronic payment, there will continue to be a need for fare boxes and collection of fares by cash or ticket to serve those that do not have a smartphone or prefer to pay with cash. The goal should be to make payment as easy as possible, and for some, cash will remain the easiest payment method.

Contribution to Integrated Mobility: Open loop payment systems, i.e., those that are not limited to payment of transit fares only, offer the potential to create single fare options across several forms of transportation or related services. For example, Chicago is exploring an option to integrate transit fares with bike share. The possibilities can further extend to combining taxi, rideshare or car share trips with transit through a single payment system.

2.2 Passenger Information

Description: There are various methods available to provide information to passengers to allow them to most efficiently manage their time. The impact of a bus running late is considerably reduced when passengers know that the bus is late and how late it will be. Schedule, trip planning, station/stops or next bus arrival information can be provided at the station/stop, on-board buses or via smartphones.

- **Real Time Passenger Information** - Real-time passenger information (RTPI) is available for transit providers and customers, and can include estimated arrival time, vehicle locations, bus schedules, crowding levels on transit vehicles and other useful information. This information can be provided on the vehicle itself, online, or at stop locations.

Real-time passenger information systems use automatic vehicle location (AVL) data to provide passengers with information on expected arrival and departure times, and/or service interruptions. The form of media used to communicate the RTPI can include websites, text messages, and smartphone applications. Public transit apps generally available today display real-time travel information including current traffic data, public transit wait times, car/bike sharing opportunities and parking availability[9].

Transit agencies have traditionally purchased RTPI and AVL systems as a single package from vendors who have held a near-monopoly. As the technology becomes more common, more options have become available. Startup companies have also entered the market to offer standalone systems for RTPI and AVL, making the implementation of RTPI and AVL more affordable than in the past. [10,11]

A 2012 study conducted by the Chicago Transport Authority (CTA) identified a 2% increase in weekday bus ridership following the implementation of the CTA Bus Tracker. The bus tracker provided the position of CTA buses in real time and expected arrival time of buses to certain stops. In Chicago, the increase in ridership from implementing RTPI technology resulted in an additional $5Million per year in fare revenue[12].

- **Journey Planners** – Most transit systems, including Saskatoon, have some form of journey planner available on the website or via a smartphone app. In the past, many systems attempted to develop their own proprietary journey planners, but the current trend is toward making the necessary data "open source" and allowing others to create apps. Open source data supports entrepreneurship and innovation. Data that is accessible allows it to be used by private app developers, agencies, the public and private sector, academia, and the general public who can create new tools, products and information approaches for customers, operators, regulators and researchers.

  Most real-time information comes from General Transit Feed Specification (GTFS) data. It provides a consistent format for transit schedules along with geographic data. GTFS is issued by almost every transit agency and is used by transit applications for smart phones to provide transit direction to passengers. GTFS feed requires information including the issuing agency, route number, route schedule, stop locations, stop times, fare attributes and transfer information[13].

- **On- Board Information** – On-board information is primarily focused on alerting passengers of the next stop via next stop signage and/or audio voice announcement. More advanced systems may include displays with real-time information, mapping, public service announcements, advertising and other information.

[9] Smartphone Applications to influence Travel Choices: Practice and Policies, FHWA, 2016
10 http://www.wri.org/blog/2016/02/real-time-transit-data-good-people-and-cities-whats-holding-technology-back
11 https://nextbus.cubic.com/News/ID/1451/5-Biggest-Benefits-of-Real-time-Passenger-Information-Systems
12 Lei Tang, Piyushimita Thakuriah, 2012, http://www.alaskapublic.org/wp-content/uploads/2012/06/bis_transit_chicago.pdf
[13] https://developers.google.com/transit/gtfs/reference/#file-requirements

Applicability in Saskatoon: Saskatoon Transit provides information on bus locations and routes throughout the City of Saskatoon via transit mobile apps. Real-time transit tracking shows customers bus locations and current wait times until the next bus arrives, to allow passengers to plan their routes and connections accordingly. A real-time application called 'Transit' is in use in Saskatoon (examples of the trip planner are shown in **Figure 5** and **Figure 6**). It helps users with the City's public transit system by providing accurate real-time predictions, simple trip planning, step-by-step navigation, service disruption notifications, and departure and stop reminders. As the BRT is implemented, real-time information on next bus arrivals should be considered at BRT stations. The City should also continue monitor trends related to trip planning integration with private companies such as ridesharing and carsharing companies.

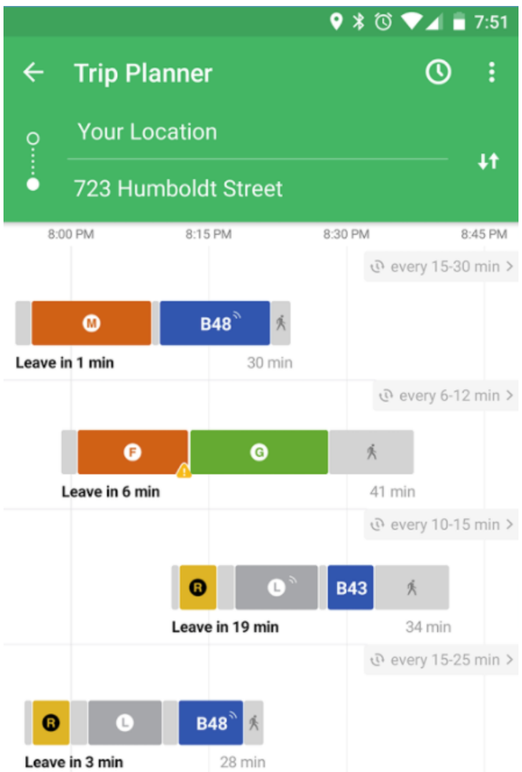

Figure 5: Trip Planner screen of the Transit App, showing transit services available for a specific trip and time of departure

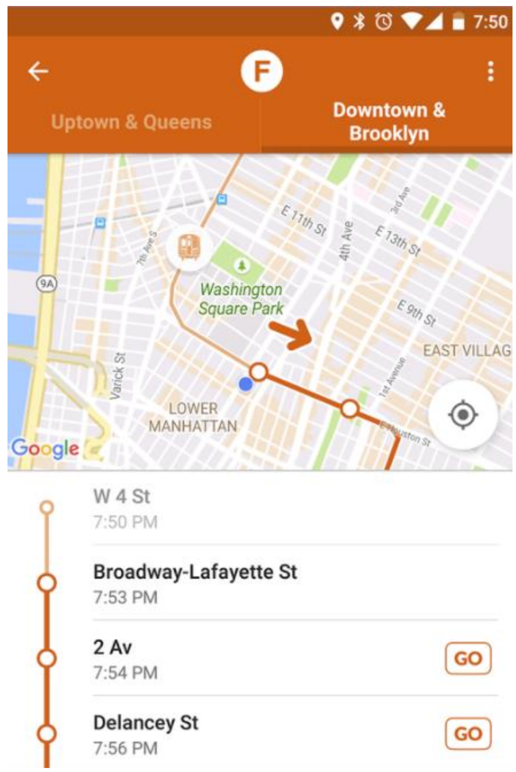

Figure 6: Transit Line Information screen of the Transit App, showing upcoming stop locations and time of arrival.

Case Study: Real Time Passenger Information – Winnipeg: Winnipeg Transit provides real time passenger information using signage at bus stops. Each sign displays bus departure times for all buses servicing the stop. As shown in **Figure 7**, the signs display the route number on the far left (item 1), with the bus destination listed in the centre column (item 2) and finally the associated departure time displayed on the right-hand column (item 3). The departure time is displayed in two formats. Buses that will arrive in less than 15 minutes are displayed as "minutes to next bus" while buses that will arrive in more than 15 minutes are displayed showing the actual time they will arrive.

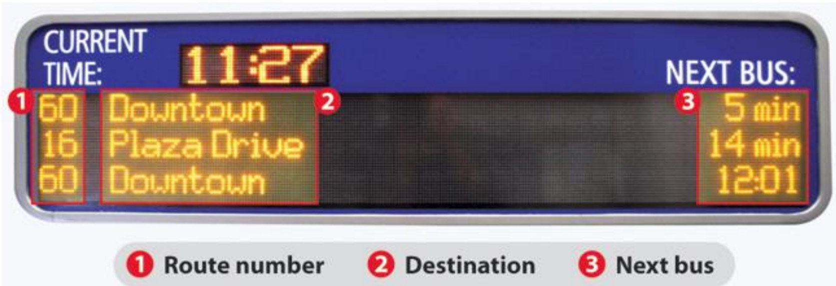

Figure 7: Real time information system of Winnipeg Transit[14]

Contribution to Integrated Mobility: Trip planning applications provide one of the best opportunities to support integrated mobility. In cities where ride sharing and car/bike sharing options are available, apps provides the flexibility of integrating these modes to allow users to request an Uber, reserve a car2go, and access the bike share system all in one place as part of an overall trip involving transit.

2.3 Transit Signal Priority

Description: Transit Signal Priority (TSP) measures improve bus operations at signalized intersections using traffic signal technology. A more complete description of transit vehicle priority measures is included in the Saskatoon BRT – Transit Priority Toolbox (August 2017). A summary is included below.

In general, TSP strategies can be categorized as passive, active, or real-time strategies. Within each group, there are a number of techniques that can be used in isolation or in combination along a given corridor to provide transit vehicles and transit routes with the necessary priority in order to increase service reliability and on-time performance, while reducing travel time.

- **Passive Priority Strategies** - Passive priority strategies accommodate transit vehicle operations by considering factors such as average transit vehicle speed instead of average automobile speed to program pre-timed signal timings. Passive priority strategies do not require advanced technology for detection or priority, and do not change with the real-time conditions of the intersection or corridor, including in the absence or presence of the transit vehicle. These strategies are low cost and easy to implement, but may also create unnecessary delays for general traffic. Passive priority strategies include:
    - ***Transit Progression*** - coordinating traffic signal timing plans on a corridor, based on transit travel time, to benefit transit vehicle progression through intersections.

[14] http://winnipegtransit.com/en/schedules-maps-tools/transittools/buswatch/

  - ***Reducing Cycle Lengths*** – shortening of cycle lengths on either the primary corridor or cross street, while maintaining the minimum pedestrian crossing time to reduce the time between transit priority phases.
  - ***Phase Splitting*** - splitting the priority phase for transit into multiple phases within a single cycle so that it occurs more frequently.
  - ***Metering*** - using a signal phase to meter the volume of general traffic entering the primary corridor to reduce a downstream bottleneck.
- **Active Priority Strategies** - Active priority strategies involve detecting transit vehicles at intersections, approval of a priority request, and modifying the signal timing plan accordingly. The process is as follows:
  - A transit vehicle detection and location system predicts the arrival time at intersections. This can be achieved via transit vehicle sensors on the roadside upstream and downstream of the intersection, or a wireless system onboard the vehicle, which emits a signal that is received by the downstream traffic signal controller through a receiver.
  - System logic then activates the priority request by transit vehicles.
  - A priority request is made by a Priority Request Generator (PRG), either a device or software that can be located anywhere in the system, including onboard, at the signal controller, or at a Transit Management Centre.
  - A Priority Request Server (PRS), typically but not always located at the controller, processes the request. A communications link between the traffic signal controller and transit vehicle is required.
  - The traffic signal controller then provides the appropriate signal timing plan.

A conceptual diagram of an active priority request using an onboard emitter is shown in **Figure 8**.

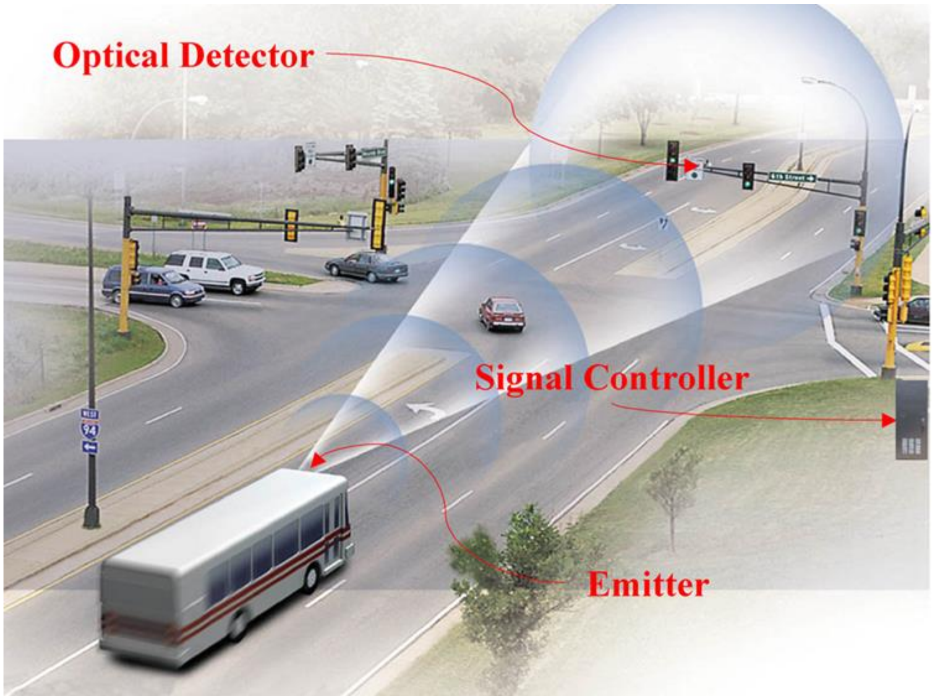

Figure 8: Conceptual Diagram of Active Transit Signal Priority Using an Onboard Emitter

Active priority strategies are described below.

- ***Green Extension*** - traffic signal controller will extend the green time for the transit priority phase when a TSP equipped vehicle is approaching, and only applies when the signal is already green for the approaching vehicle.
- ***Red Truncation / Early Green*** - truncates the red time when the transit vehicle is stopped at a red signal to reduce the time to return to the green phase.
- ***Actuated Transit Phase / Red Interruption*** - transit-only priority phase that occurs only when a transit vehicle is detected at the intersection, permitting the bus to proceed through the intersection to enter the downstream link ahead of the general traffic stream.
- ***Green Truncatio****n* - truncates the green phase when a transit vehicle is detected at a far distance from an intersection to increase the probability that the transit vehicle will receive a green phase on the next cycle when it arrives at the intersection.
- ***Phase Re-servicing*** - provides the same phase twice to give priority to transit in a signal cycle, for instance a left-turn phase or queue jump.
- ***Phase Suppression*** - eliminates a low-volume non-priority phase from the cycle when a transit vehicle priority is requested, to reduce the time to return to the green phase.
- ***Metering*** - uses a signal phase to meter the volume and time of entry into the primary corridor to provide a clear runningway for a bus.

Figure 9 summarizes active TSP strategies.

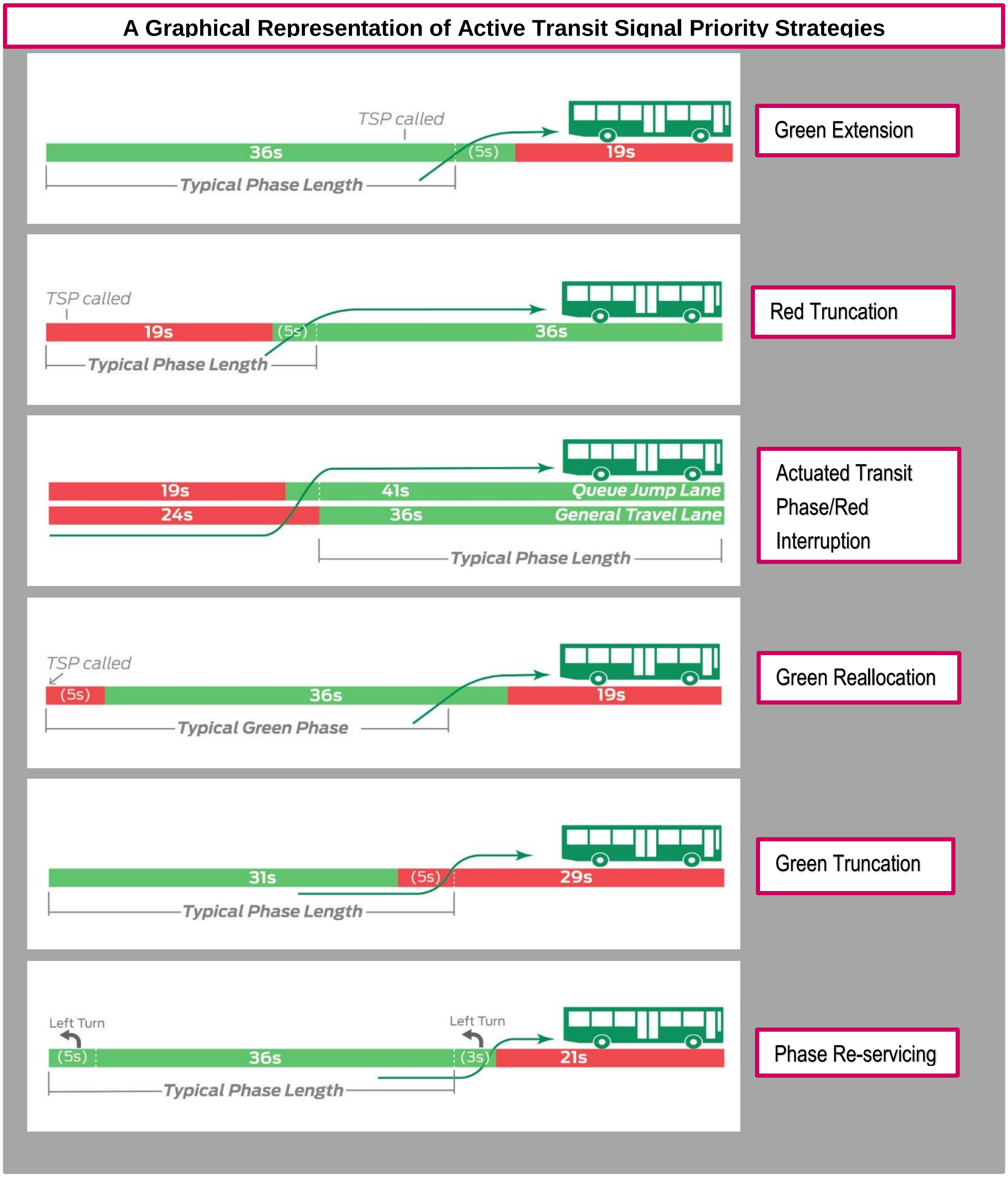

Figure 9: Graphical representation of Active TSP strategies

- **Adaptive Signal Control Systems** - Adaptive Signal Control (ASC) uses real-time information to provide transit priority by monitoring vehicle arrivals at an intersection (both transit vehicles and general traffic). TSP can be activated through the ASC system to provide transit priority while simultaneously optimizing traffic flow according to defined performance criteria (safety, person delay, transit delay, vehicle delay, or a combination of criteria). Based on these criteria, alternative signal timing plans are evaluated to select the optimal option for phase duration and sequence. When conflicting priority requests are made, conditional priority factors, such as schedule adherence, number of passengers, and route priority are used. This strategy requires ASC hardware and software, and requires a real-time traffic detection system.

Applicability in Saskatoon: The BRT in Saskatoon will include comprehensive Transit Signal Priority along the BRT corridors. TSP will ensure that the BRT operations are efficient and reliable. Travel time savings from the operations could also help reduce the overall number of buses that are required. Adaptive signal control systems may also be a consideration, with benefits to transit and general purpose traffic, but implementation and the level of sophistication required to modify the system may make this a longer term objective.

Case Studies: TSP Deployments: TSP usually supports BRT operations and reduces transit delay significantly. Total travel time can be reduced by up to 15% and delays at specific intersections reduced by up to 50%. Recent TSP studies showcase many quantifiable benefits of TSP, some of which are listed below:

- In Minneapolis, TSP applications reduced total bus trip times during peak hours between 4% and 15%
- In Toronto, a number of TSP implementation studies on streetcar routes recorded widely varying travel time improvements; up to 50% reductions in delays were observed at some intersections
- In Portland, OR TriMet was able to avoid adding an additional transit vehicle (bus) by using the efficiencies of TSP. They experienced a 10% improvement in travel time and up to 19% reduction in travel time variability. Due to increased reliability, TriMet has been able to reduce schedule recovery time
- In Chicago, the average running time of PACE buses was reduced by 15% (3 minutes) based on TSP use. Actual running time reductions varied from 7% to 20%, depending on time of day. PACE was also able to realize a savings of one weekday bus while maintaining the same frequency of service through the implementation of TSP and more efficient run cutting.
- In Tacoma, WA the combination of TSP and signal optimization reduced transit signal delay by approximately 40% in two corridors.
- The Los Angeles MTA and DOT implemented TSP on over 70 intersections of a busy 15 mile long corridor. They were able to improve operating efficiency thus reducing the number of buses required and reduced travel time.

Contribution to Integrated Mobility: TSP is primarily a strategy to improve travel time and reliability for transit. But, as it generates an overall improvement in mobility and improves transit as a mobility option, it contributes to the overall goals of integrated mobility.

2.4 Intelligent Vehicle Initiatives

Description: Intelligent Vehicle Initiatives (IVI) provide automated controls for a BRT vehicle. Technologies like Collision Warning assist a driver in the safe operation of the vehicle. Similarly, Collision Avoidance, Lane Assist, and Precision Docking functions assume direct control of the vehicle when making avoidance, guidance or docking maneuvers. All IVI functions help to reduce frequency and severity of crashes and collisions and provide reduced travel or boarding times. IVI technologies are becoming commonplace in all types of vehicles. The following describes the application of these technologies as they relate to possible applications to BRT in Saskatoon.

- **Connected Vehicle (CV) Technology –** CV technologies increase safety and optimize transit operation by allowing: wireless communication among vehicles (V2V- Vehicle to Vehicle); communication between vehicles and infrastructure, such as traffic signals (V2I- Vehicle to Infrastructure); and communication between vehicle and all other users (V2X- Vehicle to Everything), such as pedestrians.

  Transit systems have the potential to be early adopters of new CV technologies on buses as they become available. The marginal cost of the technology is relatively low when compared with the cost of a bus. Additionally, the size of a transit vehicle results in far greater blind spots when compared with a passenger vehicle, increasing the benefit associated with the additional investment in CV technology. Transit buses operate in locations with high pedestrian volumes, and often where pedestrian behaviour is unpredictable. CV technologies will protect pedestrians, particularly around bus stops.

  Many newer buses already possess advanced crash avoidance technologies, including on-board sensors, cameras and radar applications. These technologies inform and warn the operator of impending dangers so that corrective action can be taken. Emerging CV technology will intervene on the operator's behalf.

  Given the potential value of CV technology for buses, systems such as the Greater Cleveland Regional Transit Authority[15] are testing and implementing CV technologies to maximize safety. In Cleveland, vehicle-to-infrastructure (V2I) technology is being tested to avoid collisions with pedestrians in or near intersections and crosswalks. Vehicle-to-vehicle (V2V) technology will warn drivers when buses are about to be cut off. Specifically, the V2V technology will target vehicles that drive up along the left side of a bus, and then make a right-hand turn in front of it.

  As the technology evolves, the communication will go beyond monitoring the environment. It will communicate with other vehicles via short-range radio communication devices that receive and transmit information about vehicle speed, brake

[15] RTA bringing connected vehicle technology to its bus fleet
http://www.cleveland.com/metro/index.ssf/2016/10/rta_bringing_connected_vehicle.html

status, and other information that may exceed twice the range of “line of sight” capabilities to improve safety and efficiency.

The recent focus of CV technology as it applies to transit has been on safety with a specific focus on pedestrian conflicts and vehicles turning right in front of buses. As the technology evolves, V2I communication will allow the connected transit vehicles to improve mobility and benefit the environment, by directly communicating with traffic control infrastructure allowing buses to move efficiently through intersections. Once all vehicles are fully connected and communicating with the traffic management system and each other, there may no longer be a need for traffic signals.

Vehicle to everything (V2X) is the ultimate CV communication infrastructure, combining V2V and V2I, and including all types of communication between vehicles, devices on cyclists and pedestrians approaching, electricity grid and other infrastructure. The advancements in automated technology have the potential to transform transit operations. Table 2 provides a summary[16] of how categories of Automated Technology may impact transit operations.

Table 2: Technology Supporting CV/AV

Category	Characteristics and Impacts to Transit	Enabling Automated Technology
Truly connected intersections	• Communicates directly with all vehicles in real time • Ultimately eliminates traffic signals • BRT implementation will be simple with immediate phase changing	• Connected vehicle dedicated short range communications • 5G Cellular/Wireless
Truly Connected Travelers	• Communicates directly with vehicles in real time • Travel information is readily accessible • Dynamic trip requests/routing • Pedestrian warning systems • Enhanced fare payments	• Connected vehicle dedicated short range communications • Mobile phone payment systems • 4G/5G Cellular/Wireless
Transit Specific Technologies	• Retrofit pedestrian and vehicle detection and warning systems (e.g. Mobileye[17]) • All-electric vehicles • Traveler information/warning systems at transit stops	• Connected vehicle dedicated short range communications • Vision-Based Camera sensors • Bluetooth Low Energy (BLE)* • Inductive charging systems • Battery technology
Connected and Autonomous Vehicles	• V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure), V2X (Vehicle to Everything) • Operator “free” travel – eliminates or greatly reduces role of driver • Safety improvements • Reduced operational costs	• Connected vehicle dedicated short range communications • 4G/5G Cellular/Wireless • LiDAR, Radar, Vision-Based Camera sensors • Ultrasonic sensors, GPS

*Note: Bluetooth Low Energy (BLE) Beacons [18]: Small devices containing Bluetooth Low Energy technology have been utilized at transit stations across the world to improve accessibility. These devices, known as iBeacons, are

[16] The Autonomous/Connected Technology Future and HDR’s Role in Defining It

[17] Mobileye is the global leader in the development of computer vision and machine learning, data analysis, localization and mapping for Advanced Driver Assistance Systems and autonomous driving

[18] https://www.onyxbeacon.com/beacons-in-buses-tailored-public-transportation/

attached to station walls and on transit vehicles and provide notifications and audio directions through a smartphone app and Bluetooth technology to the visually-impaired. In addition to improving accessibility, some distributors offer software that give iBeacons the potential to create customized transit pricing based on destinations, route complexity, rush hour, trip duration, time, and other factors.

- **Automated Docking Systems** – Vehicle Assist and Automation (VAA) technologies have been successfully tested in several environments to guide buses, while the driver controls the speed. The precision docking was recognized as the most successful element of the testing CalTrans in Alameda County[19]. Bus operators regarded it as a valuable tool for safe and effective docking and believed it contributes personally to lower stress when docking. The VAA used two sensing technologies – magnetic markers and GPS. Other technologies that have been tried include an optical guidance system, in which a camera mounted on the front of the bus points straight down onto stripes painted on the pavement. This technology was used in Las Vegas, but was discontinued because the high temperatures prevented the guide stripes from reliably adhering to the pavement.

  Most of the automated docking technologies are part of broader vehicle guidance technologies that fall under the V2I category. However, there may be opportunities for more limited implementation of VAA for the docking function only as an early implementation. Precision docking at bus stops can provide fast loading and unloading of passengers with special needs, reducing waiting time and improving ease of access for all passengers. Precision docking maximizes the value of level or near-level platforms and minimizes damage to buses incurred at stops/stations.

Applicability in Saskatoon: Implementation of new technology across the full fleet will be challenging. A system the size of Saskatoon will require in the order of 15 years to fully turn-over a fleet of buses. However, the BRT offers an opportunity to focus new technology investment in limited areas and to a limited portion of the overall fleet, and over time evolve implementation to the full fleet. It is expected that most new transit buses in the near future will be equipped with many of the connected vehicle technologies, and as new technologies are introduced, they will also become standard features of new buses. Implementation will therefore be evolutionary in nature, but Saskatoon can make focused deployment of newer buses to the BRT routes. VAA technology, particularly associated with precision docking and guidance in limited sections of dedicated runningways, may have potential in Saskatoon. Magnetic and GPS technologies can be retrofitted to existing buses. Design and construction of the BRT in Saskatoon is considering issues that may affect precision docking and vehicle guidance, such as trees and signs very close to the side of the road (potential for bus to hit them during precision docking), placement of manhole covers and catch basins (can affect magnetic guidance) and use of rigid pavements at stations (affect guidance and passenger comfort). Even if precision docking and guidance are not immediately implemented, it is clear that technological advances will continue to evolve to a point where these features are simply part of normal transit operation. The measures included in BRT design will help to create a “future-ready” BRT corridor that will minimize the need for reconstruction later.

[19] Federal Transit Administration. Vehicle Assist and Automation (VAA) Demonstration Evaluation Report, 2008

Case Study: Vehicle Assist Automation Demonstration – Eugene OR: A test of VAA technology in real-life operating conditions was undertaken on the EmX Route in Eugene OR[20]. The 1.5-mile demonstration involved the use of magnetic sensors for precision docking at three stations and lane guidance between the stations. The VAA system was evaluated in six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including customer surveys, driver surveys and focus groups, accident reports, maintenance reports, and lane position data from the VAA on-board computer system. The components of the VAA system are illustrated in Figure 10. Key findings indicated that the VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The VAA was widely praised by the bus operators and passengers for it precision docking at the station platforms[21].

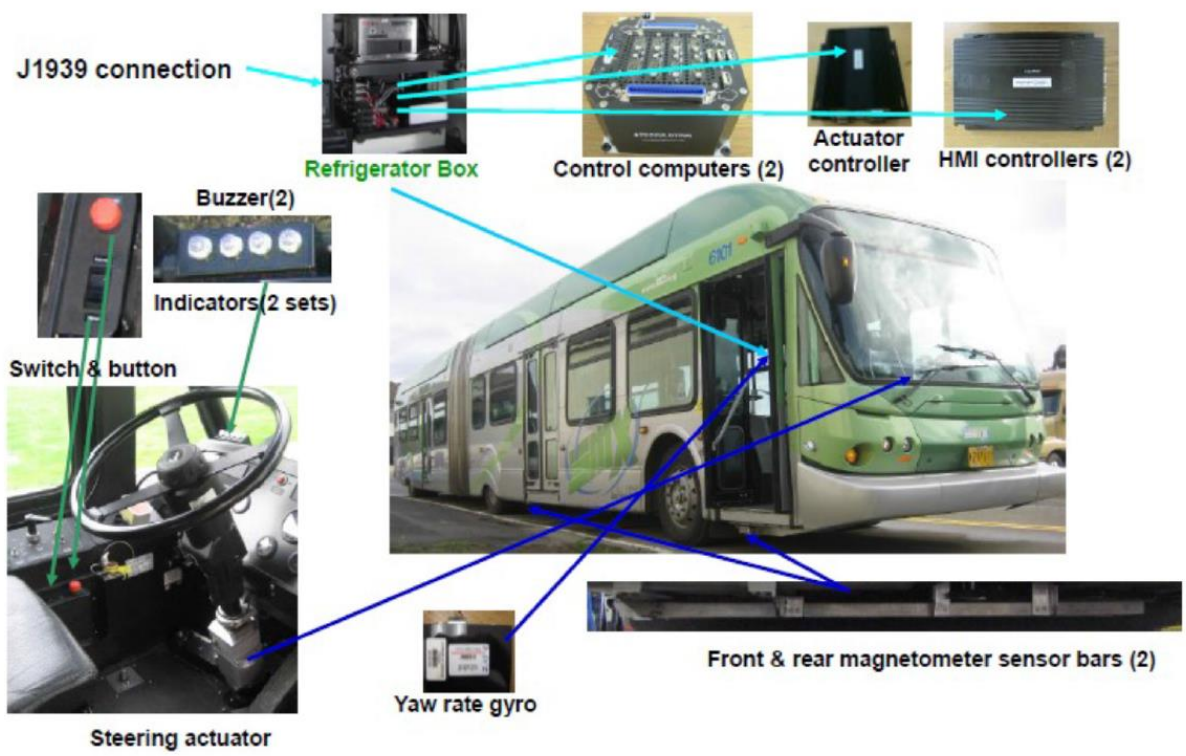

Figure 10: VAA System Components, Eugene OR *(Source: FTA 2012)*

Contribution to Integrated Mobility: The IVI technologies described for transit are also being developed for general purpose traffic. The V2V communication will rely on all vehicles being able to communicate with each other. Other technology will create safer and more comfortable environments for pedestrians and cyclists. IVI is based on full integration of all modes of travel.

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[20] Youtube video of the demonstration https://www.youtube.com/watch?v=_oKsleOocFM
[21] Federal Transit Administration, Vehicle Assist and Automation Demonstration Evaluation Report. FTA Report No. 0093. December 2012

2.5 Operations Management

Description: Operations management includes technology to enhance and automate elements of a BRT fleet management. Technology such as computer-aided dispatch can support various functions of fleet operational management. Vehicle Mechanical Monitoring and Maintenance assists in minimizing downtime of the BRT vehicles. Operations management functions improve operating efficiencies which supports a reliable service and reduced travel times.

Automatic Vehicle Location (AVL) is a means to determine the geographic location of a vehicle, through the use of Global Positioning Systems (GPS) and transmit the location using text messages, General Packet Radio Service (GPRS) or a satellite or terrestrial radio, from the vehicle to the radio of the receiver.

Computer-Aided Dispatch (CAD) is widely used to dispatch transit vehicles. It is used to send messages between the dispatch centre and vehicle operators and to retrieve data. Dispatchers are able to easily view and understand the status and location of all vehicles. AVL and CAD are proven to improve safety and security on transit vehicles, in particular due to silent alarm and video monitoring capabilities that many of these systems offer. Real-time AVL data can also be used to manage non-fixed route operations. For example, during large sporting events, buses can be dispatched when and where they are needed, to help mitigate abnormally large crowds that require public transit. CAD/AVL systems are also used to efficiently dispatch demand-response requests to vehicles, such as with paratransit riders. Knowing the location of paratransit vehicles in real time, through AVL technology, can aid transit agencies in dispatching the closest vehicle to the customer. This reduces wait times for paratransit customers[22].

Applicability in Saskatoon: AVL technology is critical to many of the transit ITS applications, including real time passenger information and some transit signal priority applications. As a first step, Saskatoon will need to investigate a modern and reliable AVL system on at least a portion of the fleet. With AVL implementation, CAD should also be a consideration. Saskatoon should continue to monitor technological changes related to AVL and CAD.

Case Study: CAD/AVL Central Ohio Transit Authority, Columbus OH: The Central Ohio Transit Authority (COTA) in Columbus, Ohio, evaluated the before-and-after effects of implementing a new bus CAD/AVL system on the efficiency and productivity of their dispatchers. With the new system there was a dramatic change in the amount of time spent each day by the dispatchers to create computer data logs of daily activity. Previously, dispatchers had written a manual log over the course of the day, which was transcribed into a computer log afterward. With the change to the ongoing automated collection of some data and the direct entry of other data into the system by dispatchers, the overall effect was that nearly 3 hours of daily work was avoided. COTA projected that over time this would allow the agency to accommodate an increase in fleet size by up to 10% with the current complement of dispatchers.

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22 https://nextbus.cubic.com/News/ID/1451/5-Biggest-Benefits-of-Real-time-Passenger-Information-Systems

Contribution to Integrated Mobility: Efficient operations contribute to the overall effectiveness and attractiveness of transit. While current CAD systems are focused on transit operations, similar systems will be required to support future integration of modes and services.

2.6 Data Collection and Monitoring

Description: Use of Automatic Passenger Counters and Archived Data can support operations and planning efforts for a BRT fleet. Silent alarms and monitoring increase the security and safety of the operation. These functions help support passenger satisfaction.

Automatic Passenger Count (APC) data provides transit agencies with information that can potentially increase the efficiency of their operations and cut costs. For example, APC data can efficiently identify underutilized bus stops to help the operator make decisions on reducing (or reorganizing) routes, vehicles, and operators, as opposed to historic methods of manual passenger counting. AVL technology can analyze past departure and arrival times to recommend more effective bus schedules, which are more accurate in their reflection of route run times than traditional methods.

Applicability in Saskatoon: While the greatest benefits from APC data come when system-wide data can be collected and analyzed, many transit systems begin with a focused automatic counting system on a limited number of buses (for example, prior to 2010, Ottawa had APCs on about 10% of buses). To keep initial investments reasonable, the BRT routes could be a primary focus of an APC program. Other transit systems have realized significant planning and system management benefits from APC systems, but like many other technologies, they come with increased staffing requirements.

Case Study: Passenger Counting System, OC Transpo, Ottawa ON: OC Transpo has been using APC systems since the 1980s. APC data are important for OC Transpo’s planners and managers, who rely on them as the primary input to all planning decisions, such as route planning, bus stop usage, shelter justification, long-range plans, and transit priority strategies. Performance standards supported by ample and accurate passenger data are important in justifying expenditures.

Contribution to Integrated Mobility: Integrated mobility relies on data. Passenger counts, particularly real-time count information can contribute to the overall data requirements of integrated mobility and evolution of smart cities.

3 Vehicle/Fuel Propulsion Technology

3.1 Technology Alternatives

Over the past decade, there has been a significant shift away from diesel buses to alternate fuels and propulsion. There are several options available:

- **Conventional Diesel –** Diesel buses are the dominant type of bus in use. They are the lowest cost option to a transit system and don't require any special infrastructure for fueling. But, diesel buses have the highest greenhouse gas (GHG) emissions of any fuel type.
- **Ultra Low Sulphur Diesel** (USLD) – USLD or "clean diesel" when used in conjunction with diesel particulate filters can significantly reduce emissions when compared with conventional diesel, to a level comparable with CNG[23]. There is some cost to convert **buses to USLD, but no special infrastructure.**
- **Diesel Hybrid Electric** – Diesel hybrid electric buses combine a conventional internal combustion engine propulsion system with an electric propulsion system. As a result of the electric propulsion, they have lower GHG emissions than conventional diesel and have longer range than electric only buses. The purchase price is very high.
- **Battery Electric Bus** (BEB) **–** These buses significantly reduce GHG emissions and are quiet when operating. They are high efficiency and have low operating and maintenance costs, but purchase costs are very high. Although technology is improving, the driving range is poor and reliability can be questionable. Significant infrastructure improvements are required to accommodate charging.
- **Compressed Natural Gas** (CNG) – CNG buses have low fuel costs and moderate bus purchase costs. GHG emissions and maintenance costs are lower than conventional diesel and comparable to ULSD. Emissions are higher than electric. Significant infrastructure upgrades are required for CNG buses.
- **Liquefied Natural Gas** (LNG) **–** Bus purchase costs for LNG are generally higher than diesel but lower than other alternative-fuel buses. Because of fueling storage requirements, significant infrastructure upgrades are required. Emissions from LNG buses are higher than other alternative fuels.
- **Biodiesel –** Biodiesel may be either pure (B100) biodiesel or a blend of biodiesel and petroleum diesel (B20). Like other alternative fuel, some infrastructure upgrades are required to support biodiesel, but they are relatively minor when compared with BEB, CNG or LNG. Biodiesel is expensive and availability can be unreliable.
- **Fuel Cell** – Fuel cell buses use a hydrogen fuel cell as the power source for the electrical drive. Fuel cells reform hydrogen from natural gas, and therefore have low fuel costs. GHG emissions are also lower than diesel or CNG. Bus purchase costs are high due to the cost of the fuel cells, and maintenance effort and costs for the fuel cells is very high. Fuel cell technology is still evolving, and current driving range is limited.

[23] Lowell, D. Clean Diesel versus CNG Buses: Cost, Air Quality & Climate Impacts, MJB&A, 2012.

As shown in **Figure 11**, diesel buses represent the largest portion of the total transit bus fleet in the United States, with natural gas buses a distant second. Electric and hybrid buses are the fastest growing type and increased more than 8 times from 2007 to 2015. The increase in both natural gas buses and electric and hybrid buses is largely due to the favourable economics and clean air benefits.

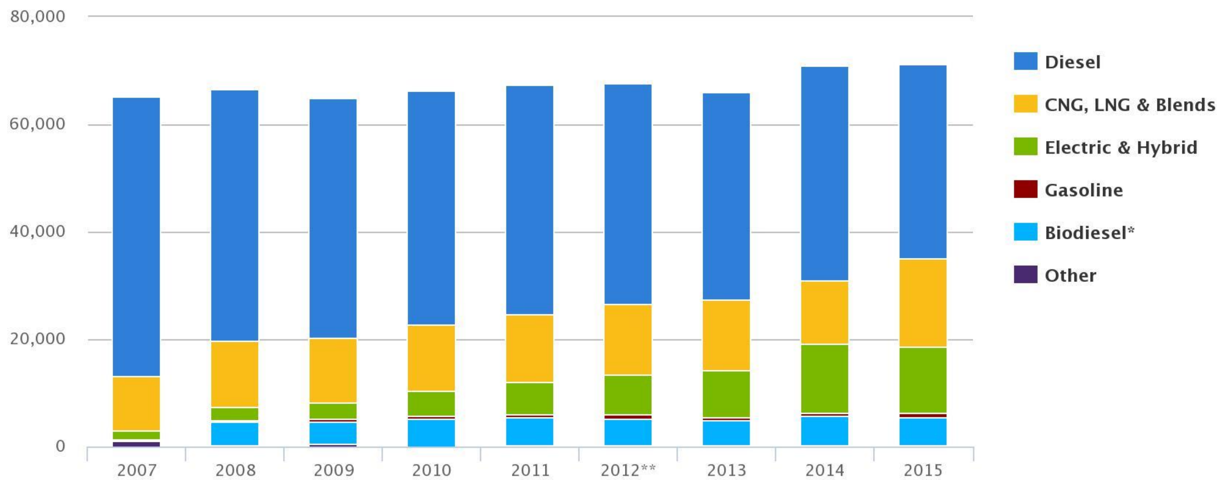

Figure 11: U.S. Transit Buses by Fuel Type[24]

Emissions benefits are one of the major motivators for the use of alternatives to diesel buses. These benefits vary depending on the type of service. For longer-distance, express services it has been found that compressed natural gas (CNG) offer greater emissions benefits, while battery electric buses have been demonstrated to have the highest emissions reduction on local routes[25].

A study by researchers at Carnegie Mellon University concluded *"that among the choices available to transit agencies, battery electric buses are the best option due to low life cycle agency costs and environmental and health impacts from greenhouse and air pollutant emissions."*[26] These findings are consistent with the current trends in vehicle propulsion for all vehicles. The following section provides additional information related to electric transit buses.

3.2 Electric Buses

Electric vehicles (EVs) have existed for over a century, but only regained popularity in recent years as advancements in technology extended the life of batteries and shortened charging time. Coupled with the decreasing price of batteries, electric buses have become a viable option

[24] Derived from the American Public Transportation Association Fact Book, 2016)
[25] Yanzhi Xu ⇑, Franklin E. Gbologah, Dong-Yeon Lee, Haobing Liu, Michael O. Rodgers, Randall L. Guensler, School of Civil and Environmental Engineering, Georgia Institute of Technology, United States. Assessment of alternative fuel and powertrain transit bus options using real-world operations data: Life-cycle fuel and emissions modeling. 2015
[26] Scott Institute for Energy Innovation, Carnegie Mellon University. Which Alternative Fuel Technology is Best for Transit Buses? 2017.

for transit. Electric buses are quieter and more environmentally friendly than diesel options, and have been deployed in numerous cities throughout Europe and Asia, as well as many parts of the United States.

Electric buses are powered solely by an electric motor and obtain energy from an on-board battery. Hybrid buses are powered by a combination of batteries and a diesel engine, in which batteries store energy and recharge when the bus decelerates, and the diesel engine provides extra energy when power requirements exceed the battery capacity.

Electric bus fleets can be categorized into two groups, based on their electric charging requirements:

- **Short Range:** Buses that require charging periodically throughout the day at convenient places along the route, such as layovers. These short-term charging periods can last 4 to 10 minutes and will allow the bus to travel about 50 km. Examples are shown in **Figure 12** and **Figure 13.** Charging duration and range depends on the driving distance, potential traffic congestion, climate conditions and size of batteries
- **Long Range:** Buses can travel over 500km in one charge and therefore do not require interim charging during their daily operations. These buses need to be charged overnight or days prior to travel depending on the length of the routes they serve

Figure 12: Fast Charging Station using plug-in DC charger

Figure 13: Electric Buses in Montreal at their top-down pantograph charging stations[1]

Current trends are toward a combination of fast and slow charging, where buses are fully charged overnight and fast-charged in-route to maintain sufficient range.

Table 3 and **Figure 14** provide an overview of costs and benefits associated with the use of electric buses and compare electric buses to diesel buses for reference.

Table 3: Comparison of Electric and Diesel Buses[27]

Factors	Electric Buses27,28		Diesel Buses29
	Short Range	Long Range	
Capital Costs • **Bus Cost** • **Fast Charging Station Cost**	$800,000 $750,000-$1,000,000		$450,000
Fuel/Electricity Cost (Over 12 years)	$78,000		$378,000
Maintenance Cost (Over 12 years)	$252,000		$420,000
Total Costs	$1,180,000		$1,348,000
Charging time	4-10 min	Overnight*	n/a
Range	50km	500km to over 1,000km	n/a

*Technology continues to evolve and with charging times becoming less and range increasing.

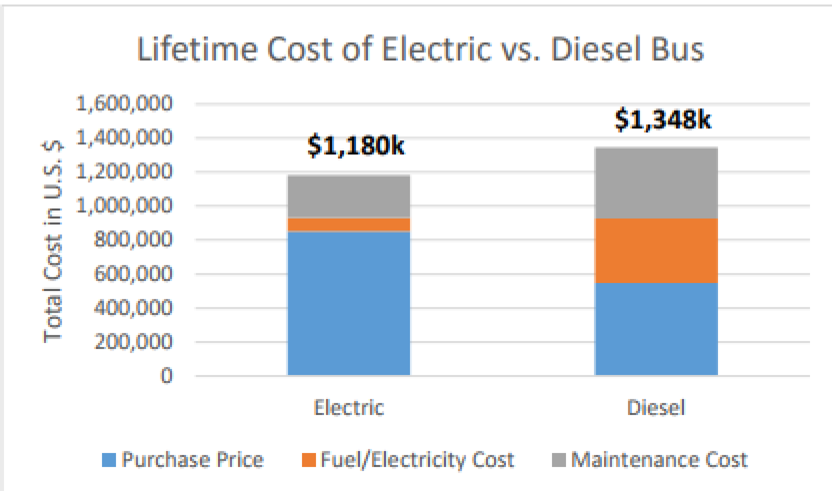

Figure 14: Lifetime (12 year) costs of electric versus diesel buses, excluding cost savings associated with health benefits[27]

The use of electric buses reduces Greenhouse gas (GHG) emissions in comparison to diesel-fueled buses, but also offer an extra benefit in reducing health care costs related to vehicle emissions. A recent study showed that the projected annual benefit to New York City from making the switch to electric buses is approximately $150,000 per bus per year, based on the Environmental Protection Agency's Diesel Emissions Quantifier tool[30].

Despite the benefits related to electric buses, some challenges remain. Electric buses have higher initial purchasing costs. Batteries degrade over time and their lifetime performance is

[27] http://www.gohart.org/Style%20Library/goHART/pdfs/board/Presentation%20CNG%20Verses%20Electric%20Bus.pdf
[28] http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf
[29] https://www.thoughtco.com/bus-cost-to-purchase-and-operate-2798845
[30] http://blogs.ei.columbia.edu/2016/05/31/going-electric-adds-up-to-a-good-idea-for-nyc-buses/

uncertain. In cold climates in particular, the electrons in batteries slow, resulting in reduced energy output, slower charging times and significantly reduced hauling power and range.

For temperatures around freezing, the output of lithium batteries is reduced by 10%. At -30°C, the output is reduced by 25%. At -20°C charging time is 20 times slower than at +20°C. In colder climates, buses must also be able to heat the passenger compartment. In Montreal, it was determined that in-route charging as well as on-board heaters were needed to maintain sufficient range. Some bus manufacturers include a diesel power unit for passenger heat, which may be effective, but generates emissions.[31]

Examples of electric buses in other jurisdictions

A number of cities around the world are currently considering, or are in the process of, changing their diesel fuel base buses to electric buses. These cities, including Chicago, London, Vienna and Los Angeles, are gaining valuable experience in the implementation and use of electric buses, and should be consulted to gain a strong understanding of their experiences. Many other cities around the world have also taken initiatives or begun exploring the implementation of electric buses.

The Antelope Valley Transit Authority in northern Los Angeles is planning to convert its entire fleet of 85 diesel buses to all-electric buses, the first transit authority in the country to convert completely. Currently they are seeing a savings of US $46,000 per bus per year from operations.

Experiences of other transit authorities (including London and Paris) over the past few years with battery electric buses has been very positive. The Toronto Transit Commission recently announced a goal to have the entire bus fleet of 2,000 vehicles be emission-free by 204032. Montreal is the first Canadian city to operate fully electric buses (3 buses on the 36-Monk Line). They also recently announced that by 2025, 40 additional electric buses will be added to reach their strategy for electrifying Montreal's surface transit systems. Edmonton has a goal begin purchasing only electric buses starting in 2020, once a new garage is constructed with the ability to charge and service electric buses.

Applicability in Saskatoon: Saskatoon Transit currently operates a fleet of approximately 140 diesel buses on 23 bus routes. As electric battery technologies improve to provide longer travel range, fast charging and effectively operate in cold climate, Saskatoon Transit should consider the wider benefits of adopting electric buses. In this process, the City should turn to other cities in Canada that experience similar weather patterns and are already testing these technologies. Montreal, Edmonton and Toronto have been working with electric bus technology in cold environments and would serve as good resources. Saskatoon should continue to monitor

The Carnegie Mellon University (2017) research provides good direction for transit agencies that are considering electric bus strategies. **Table 4** provides recommendations from the research are directly applicable to Saskatoon:

[31] http://blog.ballard.com/battery-electric-bus
[32] Green Bus Technology Plan, TTC Staff Report, City of Toronto, 2017

Table 4: Short term and long term strategies related to vehicle propulsion

Short Term Strategies	Long Term Strategies
Wait and Observe – learn from the implementation experience of early adopters	Invest in Battery Electric Buses – it is expected that costs will decrease and range will increase as the technology improves
Plan Ahead – changes in garage infrastructure and operational scheduling may be necessary to allow for battery charging; anticipating and planning for changes will help in the transition	Investigate Renewable Energy Sources – a switch to battery electric buses will increase the emissions contribution from the generation of electricity, therefore other sources of electricity should continue to be investigated
Test the Options – test buses before making a major investment to make sure Saskatoon's needs will be met	
Update Studies – review updated studies as better data on costs, performance and emission are available so that decision making is based on the most current information	

4 Emerging Technologies and Mobility Trends

Advancements in technology, particularly mobile technology over the last decade, have created a number of new products and services that will influence how people will travel and the travel mode(s) they choose. Although these emerging technologies and trends are not all directly applicable to transit, they all contribute to integrated mobility and therefore will affect how transit fits into transportation systems of the future.

New mobility services and products examined include new mobility service models, including car sharing, bike sharing, ride sourcing, demand responsive transit and others; and Connected and Autonomous Vehicles (CV/AV).

4.1 New Mobility Service Models

New mobility service models fall under two distinct categories: individual-based mobility and group-based mobility.

4.1.1 Individual- Based Mobility

Individual-based mobility includes services such as **carsharing, bike sharing and ridesharing.**

- **Car Sharing** - Car sharing fleets are typically owned and operated by a single organization and they offer many benefits compared to traditional car rental businesses. Car sharing models are either two-way or one-way. Two-way car sharing models require users to pick-up and return cars to the same location. With one-way car sharing model, vehicles are located throughout a city and users can pick it up in one location and drop it off at a different location. The car sharing model provides an improved accessibility system for unlocking the vehicles. Usually through a smartphone or a Radio Frequency Identification (RFID) card, it allows users to access the system and the car sharing service at any time of the day.

  In 2015 the University of California (UC) Berkeley published a study that documented the behaviour of people with car share memberships. The study investigated the mode customers would use if the car share service did not exist. The results are summarized in **Table 5**. These diversion behaviours are anticipated for employees and residents that have car share memberships.

Table 5 Car Share Diversion Behaviour

If Zipcar did not exist, I would have:	
Borrowed a car	14%
Take public transit	18%
Used a traditional car	37%
Used my personal car	10%
Taken a taxi	12%
Other	7%
Walked or biked	2%

Based on the research statistics, 18% of car share trips are diverted from transit, 2% from active transportation, and the remaining 80% from vehicular trips (ranging from taxi, car rental / borrow, or personal car). According to the UC Berkeley study by *Shaheen et. al*., two in five car share members surveyed sold or postponed a vehicle purchase. These statistics indicate a strong shift away from personal vehicle use where publicly accessible car share is available.

Examples of Car Sharing services in Canada: There are several car sharing services operating in Canada, including Enterprise CarShare, Zipcar and Car2Go. Car2Go offers the most flexible service, allowing users to take any available car closest to them without a reservation. It also allows users to park the vehicle at any approved legal spot within the designated boundary area, instead of returning it to a designated parking space.

As shown in **Figure 15**, the blue border outlines Car2Go's Home Area in Calgary. Cars can move around and park freely within the limits of the border. Trips can't terminate beyond the border limits, with the exception at special car2go-dedicated Parkspots, such as at the airport in the case of Calgary.

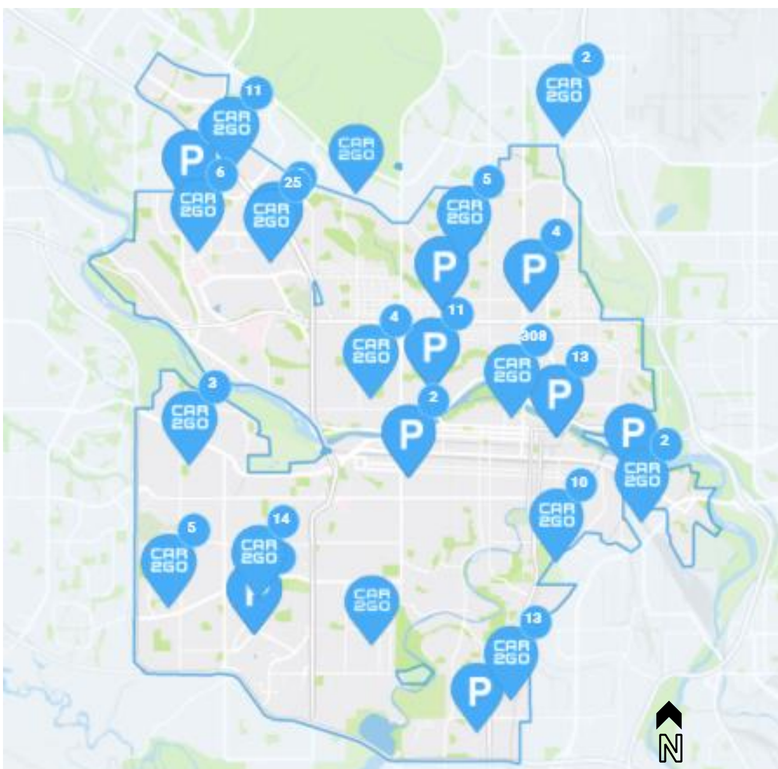

Figure 15: Car2Go in Calgary

- **Bike Sharing** - Bike sharing services follow two models, similar to car sharing services. The first bike share model uses a system of fixed stations located across a designated service area, where users can rent and return a bike at whichever location they choose. The second bike share model is a "dockless" model, which allows users to find and checkout bikes using a mobile app and leave them anywhere within the designated area (similar to Car2Go).

Bike share services have the opportunity to divert trips from other modes and generate new trips. Based on a study in Philadelphia completed in 2010, diversion rates from alternate travel modes to bike share, and number of new trips generated due to bike share mode were identified. **Table 6** identifies the percentage of trips that switched from other modes as a result of introducing new bike share services for low, middle, and high bike share demand scenarios.

Table 6: Bike Share Diversion Rate for Low, Middle, and High Demand Scenarios[33]

Mode	Low	Middle	High
Bus or subway	1.4%	3.8%	4.6%
Car or motorcycle	0.06%	0.14%	0.18%
Private Bicycle	1.8%	2.6%	3.4%
Walk	0.48%	0.56%	0.64%
% of total diverted trip volume for all above modes	1.1%	2.2%	4.4%

Note: For trips diverted from private bicycles, the high scenario reflects a doubling of the base traffic zone level bicycle trip volumes to which this 3.4% rate was applied in order to reflect anecdotal doubling of citywide bike trips since the 2000 Household Travel Survey

Transit in particular is impacted by bike share services according to the research conducted in Philadelphia. While it may provide an alternative to shorter distance transit trips, bike share can also be a critical solution for the start and end of transit trips, the first mile and last mile connection. For BRT services and other high order transit that have stops spaced farther apart compared to conventional bus services, providing good first mile/last mile connections will encourage transit use.

Examples of Bike Share systems in Canada: Bike Share Toronto is an example of a bike sharing service using the “fixed station” model. It allows users to pick up and return a bike at any of the 200 stations located across the City of Toronto.

Toronto has a second bike share system, called Dropbike. It is a “dockless” system, which was implemented in the summer of 2017, and allows bikes to be left at designated “havens” – bike posts and racks marked in the app. The initial price for rentals is $1 per hour[34].

In Hamilton, Ontario the bike share system “SoBi”, which stands for Social Bicycle, offers a hybrid version of the two models as bikes can be picked up and returned at a station, or locked at a regular bike rack for an additional service fee. Figure 16 illustrates the user interface of the SoBi bike share app, which shows number available bikes at docks and at other locations within the City of Hamilton.

[33] Philadelphia Bikeshare Concept Study, JzTI and Bonnette Consulting with Delaware Valley Regional Planning Commission, February 2010
[34] Hains, D. New Bike Sharing System Will Debut in Toronto Later This Summer. Metro, May 17, 2017.

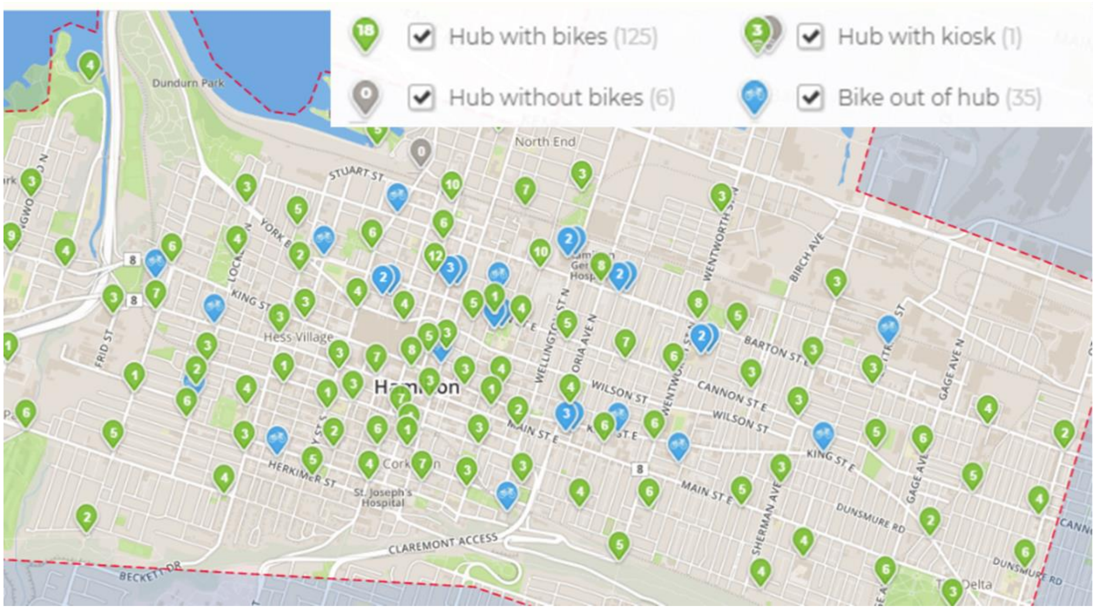

Figure 16: Bike share system Sobi Hamilton [35]

The City of Saskatoon completed an Active Transportation Plan in 2016 that will guide the development of bicycle network for the City. The proposed network is shown in Figure 17. The City does not currently have plans to implement a bike share program. If that possibility arises in the future, the City will need to evaluate locations for bike docks. Good candidates for bike docks are along existing or proposed bike paths, and at BRT stops to encourage connections to the transit system.

- **Ride sharing / Ride Sourcing** – Ride sharing or ride sourcing is an evolution of traditional taxi models. It provides a range of private transportation services which users can typically access with the use of computer or mobile applications. Lyft and Uber are two of the major ride sharing companies in North America, with Uber being the primary provider in Canada.

  There are no ride sharing service such as Uber currently operating in the Province of Saskatchewan. However discussions are underway, and legislation and regulations are currently being considered. According to a recent survey conducted by Nanos Research published in November 2017, 68% of 400 respondents reported that they were supportive of ridesharing and about 53% noted that ridesharing would decrease impaired driving rates.

[35] https://hamilton.socialbicycles.com/

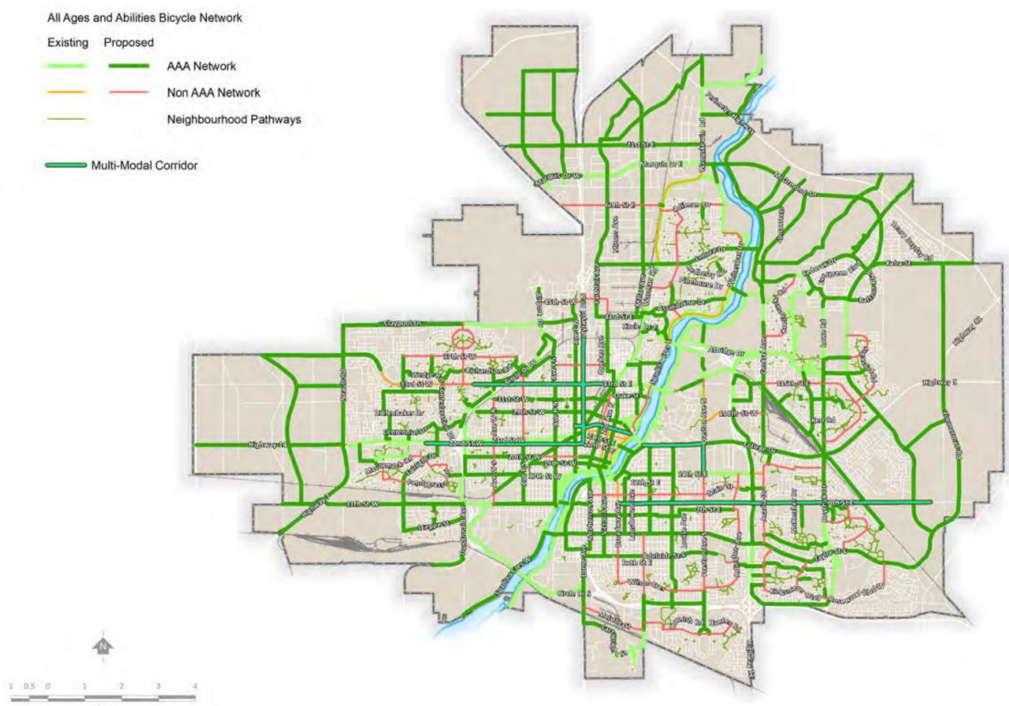

Figure 17: Proposed All Ages and Abilities Bicycle Network[36]

4.1.2 Group-Based Mobility

Group-based mobility implies the shared use of a vehicle. Group-based mobility often includes various forms of shared ride sourcing, including carpooling and vanpooling, and on-demand ride services. It can also include alternative transit services, such as demand responsive transit and private transit services.

- **Shared Ride Sourcing** - Shared ride sourcing services use many of the same principles as individual ride sharing. However, shared ride sourcing allows riders travelling in the same direction to share a vehicle and thus reduce the cost. Ride matching is done using algorithms hosted on the company's server to match users. UberPOOL is currently the only shared ride sourcing serving operating in Canada. Users can request the service on their mobile device and the algorithm will match them with other users heading in the same direction, with a maximum of 2 riders per pickup. The text box presents an example of shared ride sourcing in the Town of Innisfil, Ontario.

[36] Active Transportation Plan, City of Saskatoon, 2016

Shared Ride Sourcing Case Study: Town of Innisfil, Ontario

The Town of Innisfil has a population of approximately 36,000. It was the first municipality in Canada to partner with Uber and local taxi companies to provide demand-responsive ride sharing service as an alternative to implementing a high-cost fixed-route bus service. In 2017 the Town initiated a 2-year pilot program. Residents using the program can use the UberPool on-demand ride sharing platform, which connects drivers with passengers/ commuters travelling in the same direction, generally towards major destinations such as the Town Hall and GO transit stations as shown in Figure 18. Each rider pays flat fare rates ranging from $3 to $5 per ride and the Town covers the difference between the base fare paid by the resident and the Uber or taxi fare. In addition to trips to specific destinations, the Town of Innisfil subsidizes a portion of the fare for any trips taken by residents within the Town. The budget for the pilot program is $100,000 in 2017 and $125,000 in 2018.

Figure 18: Uber/Taxi Pick-up and drop-off locations at the Town of Innisfil[37]

- **Demand Responsive Transit (DRT) –** DRT provides a flexible routing and scheduling service. Currently in Canada, many transit agencies use DRT for paratransit programs. There are a growing number of examples across Canada where the application of demand responsive service is expanding to replace or complement unviable fixed route operations. For example, York Region Transit replaced some of the conventional routes in lower density/lower demand areas with DRT service that picks up online on a fixed route or at a predefined stop. In Winnipeg Dial-A-Ride (DART) buses operate during off-peak hours and provide service to/from transit transfer points.
- **Microtransit** – Microtransit and DRT services are often grouped together as they have many common elements. However, to distinguish between the two, DRT services often require pre-booking, unlike microtransit services that use more technologically advanced routing methods. Microtransit encompasses flexible transit services that use small buses and develop routes based on customer input and demand. Microtransit companies are often private and unsubsidized and current examples are generally not integrated with existing transit services. Most commonly known microtransit service providers include Chariot in San Francisco and until recently Bridj in Boston. Microtransit routes can either be fixed or operated in a demand responsive manner, such in the case of the Chariot

[37] Global News, 2017

model. In this case, routes are created using crowd sourcing techniques, which enable the company to collect information about a potential route or a project by enlisting the service online and surveying potential users to determine if there is demand for this route/project.

Bridj recently ceased operation. There are many possible reasons for its failure, but it seems that an advanced routing algorithm is not enough to overcome the challenges of most demand-responsive services – the lack of directness in the route. DRT services are often implemented to meet coverage objectives of a publically funded transit system, and are typically the highest subsidized rides in the system.

Example of microtransit model in Canada: There are examples publically-funded, and subsidized microtransit services to provide "last-mile" connections. The Town of Milton, Ontario and Metrolinx launched a one-year microtransit pilot program for the first and last mile service to and from the Milton GO Station. The pilot service ran from May 2015 to April 2016, and used shuttles operating on dynamic routes based on the real-time pick-up and drop-off requests from customers. The Town invested $125,000 to allow customers of the commuter rail service to share taxi rides to and from Milton GO Station through the use of an app. Over the one-year period, the pilot project observed a shift in service by approximately 5% of auto drivers to the microtransit program. It was deemed a success as it demonstrated that providing access solutions to high order transit stations can reduce auto access share and relieve parking demand. Upon completion of the pilot program, the Town re-implemented afternoon / evening GO connect drop-off service and is looking for future pilot initiatives.

4.1.3 Mobility-as-a-Service (MaaS)

Mobility-as-a-Service (MaaS), also known as Transportation-as-a-service (TaaS), describes a paradigm shift in the transportation, moving towards mobility solutions to replace privately owned modes of transportation. MaaS provides an integrated platform for users to plan trips, monitor progress and pay for the service (either through a subscription package or as an individual trip). Under this concept users won't need to worry about topping up smart cards, nor buying individual tickets. Research suggests that by 2030, about 95% of passenger miles traveled in the U.S. will be served through on-demand transportation systems owned by fleets, very much like MaaS[38].

MaaS is data-driven user-centered, and powered by the growth of smartphones. In order to work efficiently, MaaS would require the following conditions[39]:

- Smartphones on and a mobile application,
- Internet access to all smart phones,

[38] Rethinking Transportation 2020-2030, Retrieved from, https://static1.squarespace.com/static/585c3439be65942f022bbf9b/t/591a2e4be6f2e1c13df930c5/1494888038959/RethinkX+Report_051517.pdf
[39] The Rise of Mobility as a Service, Retrieved from, https://www2.deloitte.com/content/dam/Deloitte/nl/Documents/consumer-business/deloitte-nl-cb-ths-rise-of-mobility-as-a-service.pdf

- High levels of connectivity on the transportation systems (in terms of modes, services and fares),
- Real-time travel information that is secure, dynamic and up-to-date to inform on travel options, schedules, and updates,
- Cashless payment systems via apps.

The following text box provides an example of a mobile app in Helsinki Finland that provides MaaS service.

Mobility-as-a-Service Case Study: Whim App at Helsinki, Finland

Whim is a Mobility-as-a-Service (MaaS) app that helps users plan their trips by analyzing all locally available transportation modes in a single platform. Since June 2016, Helsinki residents have been able to use Whim to plan and pay for all modes of public and private transportation within the city, including train, taxi, bus, car share, and bike share. Anyone with the app can enter a destination and select his or her preferred mode of getting there. Whim offers different pre-paid monthly plans, or a pay-as-you-go option, as shown in Figure 19.[40]

Figure 19: Whim Mobile App in Helsinki Finland [27]

4.2 Connected and Autonomous Vehicles

Vehicle automation is an emerging technology that will drastically change the transportation network and travel behaviour. Among all technological advancements, connected and autonomous vehicles (CV/AV) are probably the most widely discussed and debated topic, yet the most inconclusive in terms of their function in the transportation system and potential effect on travel behaviour and traffic implications. Connected vehicle technology is rapidly becoming common in all types of vehicles and the technologies for transit buses as discussed in Section 2.4 will apply to all vehicles. As CV technologies mature, V2X communication capabilities will be an important element of the communication infrastructure for all vehicle types.

CV/AVs could also enhance, facilitate or replace some conventional transit service. For example, AVs could provide service for first mile/last mile trips and connect to high order transit

[40] https://whimapp.com/fi-en/

stations, possibly as microtransit services. They could also replace some of the low demand transit routes with automated DRT services. In the foreseeable future, it is possible that the driving function for some transit services could be replaced by AV technology, but human interaction will remain a requirement for customer information and support, fare collection, enforcement and passive security, such as on Vancouver's SkyTrain (which is driverless).

There are still many unknowns in terms of timing, ownership models, and how CV/AV will impact travel patterns, the network and our communities. The greatest uncertainties are associated with driverless or fully autonomous operation.

There are six levels of autonomous driving as outlined in **Table 7**. Level 0 describes vehicles with no automation, where the human driver is responsible for all operations. Levels 1 and 2 have autonomous features that assist in steering, acceleration and deceleration. For levels 3 to 5, the vehicle is more capable of monitoring the driving environment, and the computer is able to take control and respond to changing surroundings. Level 5 is full automation where the car does not require a driver for any guidance. Currently, only vehicles in which drivers can shift safety-critical driving functions to the vehicle under certain environmental conditions (Level 3) are commercially available.

The topic of fully autonomous vehicles has generated considerable media attention. There is research underway globally to identify potential issues, legislation, and other impacts of CV/AVs. Many of these issues will need to be addressed before fully autonomous vehicles become widely adopted.

Table 7: Six Levels of Automation according to Society of Automotive Engineers (SAE)[41]

(SAE) Level	Type of Automation	Narrative Definition	Execution of Steering and Acceleration Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment, and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	System(s)	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	Syste m	Human driver	Some driving modes
4	High Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	Syste m	System	Some driving modes
5	Full Automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	Syste m	System	All driving modes

Beyond the obvious policies and legislation regarding autonomous vehicles, there are less obvious policy and infrastructure needs that require change. For example, the majority of autonomous vehicle technologies rely upon clear lane demarcations to identify lanes. Current construction practices for the reconstruction or resurfacing of roadways may have a several day

[41] Source and credit: Society of Automotive Engineers (SAE) International standard J2016

delay between finishing the reconstruction or resurfacing, and painting / striping of the lane. Deployments and first-adoption will go to those locations that are “technology friendly” and have policies and standards in place for utilization of the technology. In many jurisdictions, such as in California, it may be illegal to operate an autonomous vehicle without first receiving an exemption to State law. Conversely, other states, such as Nevada, have relaxed legislation and policies to facilitate autonomous vehicles. In Canada, the Ontario government gave permission to the testing of automated vehicles on-road to support deployment on January 1, 2016, and further advancements were made as the Ontario Ministry of Transportation announced the first of three participants approved to participate in Ontario’s Automated Vehicle Pilot in November 2016.

Although full CV/AV implementation is years, if not decades away, opportunities exist for cities and agencies to explore CV/AV concepts through pilot programs. Examples from the US include cities such as Las Vegas, Miami, Columbus and Tampa, where autonomous transit vehicles are being deployed to provide first/last-mile connections. Fleet operations like transit and trucking have the potential to be early adopters of CV/AV technology. The ability to create V2V communication within the fleet and the potential for operation in dedicated lanes and roadways (such as transitways) will support technology adoption before general traffic and personal vehicles are able to widely interact in a CV/AV environment.

5 Mobility Hubs

Rapid adaptation of integrated mobility, particularly smart technology based on shared or on-demand service, is changing the current auto-oriented paradigm and raising the concept of "Mobility Hubs".

A Mobility hub is a one stop service point or station for the integrated multi-modal system to address the "first and last mile" problem while incorporating multiple systems at a small or large scale, as illustrated in **Figure 20**[42]. This hub includes:

- Designated waiting areas for demand responsive transit or carpooling
- Fixed-route transit service (local transit)
- Car share stations
- Bike share stations
- Electric Vehicle Charging facilities
- Transit Screens that display information on all modes of transportation in real time

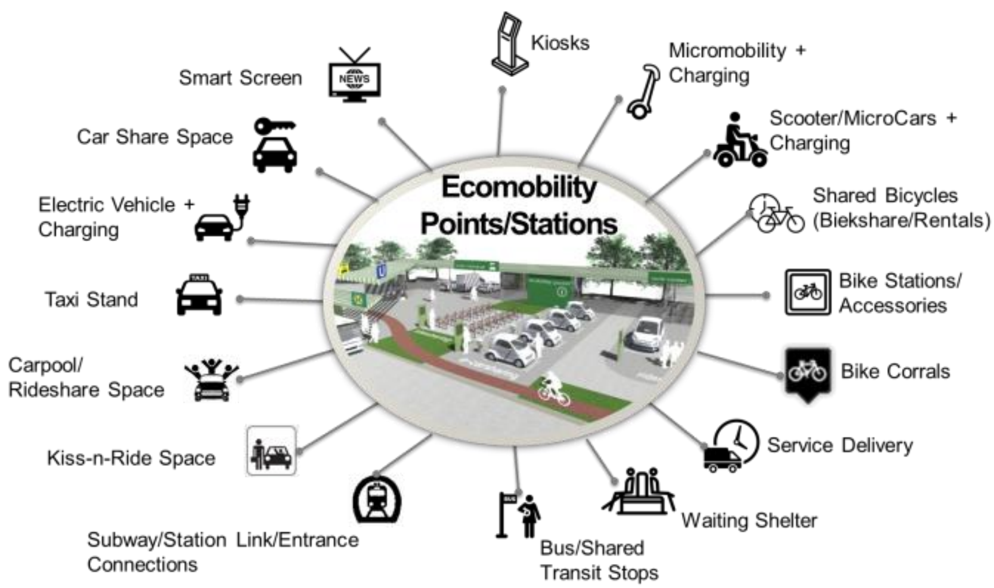

Figure 20: Conceptual Mobility Hub and its elements[43]

Mobility hubs have the potential to improve the transit experience for providing the first and last mile connections. Leveraging this emerging mobility technology, the City of Toronto's Consumers Road Business Park has recently initiated a pilot program to implement several eco-mobility hubs in large and small scale as shown in **Figure 21**.

[42] Karim D. M., Creating an Innovative Mobility Ecosystem for Urban Planning Areas, Disrupting Mobility - Impacts of SharingEconomy and Innovative Transportation on Cities, Springer Book, Lectures in Mobility, ISBN: 978-3-319-51601-1, pages 21-47, 2017.

[43] Karim D. M., Innovative Mobility Master Plan: Connecting Multimodal Systems with Smart Technologies, Disrupting Mobility Conference, MIT Media Lab, Cambridge, USA, November 11~13, 2015.

Through the establishment of Transit Villages, Saskatoon has taken early steps to supporting development to Mobility Hubs. The principles being applied to the Transit Villages planning has many similarities to the planning in Toronto and is creating readiness for future Mobility Hubs.

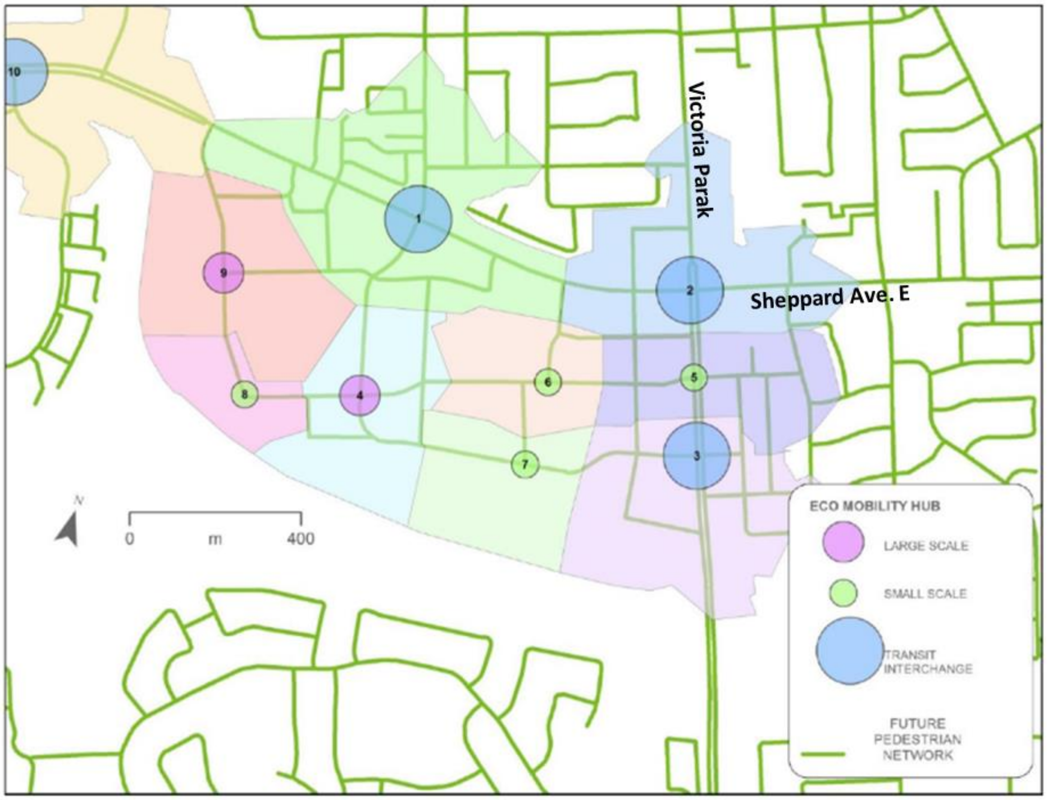

Figure 21: City of Toronto's ConsumersNext TMP Mobility hub plan[44]

[44] Consumers Next Transportation Master Plan, final report, City of Toronto, 2017

Mobility Systems Case Study in Quayside Toronto

Sidewalk Labs, a division of Google's parent company Alphabet Inc., recently received approval from the City of Toronto to redevelop Toronto's waterfront, bringing smart city technologies to Quayside, Toronto. Quayside would be a new smart neighborhood, located at Parliament Slip, just southeast of Downtown Toronto. Sidewalk Labs aims to bring the innovations advanced at Quayside across the Eastern Waterfront, which is more than 325 hectares (800 acres) and represents one of North America's largest areas of underdeveloped urban land. Their vision is to develop a complete sustainable neighborhood with advanced solutions for transportation. Sidewalk Labs' vision for mobility represents a paradigm shift, moving towards a car-free neighbourhood in Quayside. Sidewalk Labs plans to use both traditional transit systems as well as new digital mobility tools, to offer efficient alternatives to driving at lower costs than owning a car. For trips within the neighbourhood, self-driving transit shuttles together with robust walking, cycling infrastructure and bike sharing facilities are anticipated to facilitate short-distance trips and support the transit system. For trips outside the neighbourhood, Sidewalk Labs' priority is to reduce the need for privately-owned cars. As such, a Mobility-as-a-Service platform will facilitate an on-demand ridesharing system. These initiatives will apply smart city principles to help make this neighbourhood the most auto independent neighborhood in Toronto.[45] An illustration of the vision for Quayside is provided in **Figure 22.**

Figure 22: Smart City at Quayside, Toronto mobility vision[46]

[45] The Sidewalk Labs Vision Sections of RFP Submission Report, 2017
https://sidewalktoronto.ca/wp-content/uploads/2017/10/Sidewalk-Labs-Vision-Sections-of-RFP-Submission.pdf

[46] The Sidewalk Labs Vision Sections of RFP Submission Report, 2017
https://sidewalktoronto.ca/wp-content/uploads/2017/10/Sidewalk-Labs-Vision-Sections-of-RFP-Submission.pdf

6 Conclusions

As the City of Saskatoon continues to grow and urbanize, the City's BRT and Transit Plan initiative is setting the stage for the City to consider additional supportive innovations in technology and mobility. In an era of rapid technological changes, the City has numerous options to consider. While it may be desirable to be the first to implement new technologies, this can be risky and result in very costly investments with little gain. Because Saskatoon Transit is not large enough to be in the research and development business, the recommended approach for Saskatoon is to closely monitor the progress of other municipalities to learn from their experiences to identify the key investments that will make a lasting impact on Saskatoon.

This report identifies a number of key findings for the City to consider for further study and consideration:

Take advantage of "leap-frogging" technology. Two examples of where Saskatoon may wait on technology include the areas of alternative fuels and propulsion and smart payment. Saskatoon will be better served to wait and evaluate the progress on electric buses rather than investing in alternative fuels in the short term. Similarly, while smart cards have become a popular fare payment method over the last decade, Saskatoon has an opportunity to skip the smart card "phase" and go directly to smartphone fare payment technologies. The smartphone electronic ticket similar to the application being considered in Calgary represents a practical initial step toward fare payment by smartphone.

Implement innovations in BRT Design and Operations. Automatic Vehicle Location (AVL), Real Time Passenger Information (RTPI), and Automatic Passenger Counting (APC) are essential elements of BRT implementation and are rapidly becoming expectations of all transit systems. Saskatoon should closely monitor advances in these areas to make sure its systems remain current and applicable to Saskatoon's needs. Transit Signal Priority and Adaptive Signal Control Systems where signal control is being upgraded should be implemented to maximize efficiency and speed of BRT operations. Finally, Precision-docking systems require well-planned and designed stations that will allow buses to be very close to the curb. These considerations can be applied to station design, even if precision-docking is not planned for the immediate future.

Implement land use policies that support the creation of Transit Villages surrounding BRT stops to complement BRT services and the creation of future Mobility Hubs integrating shared mobility services.

Continue to monitor and investigate evolutionary technologies in the Saskatoon context as technology matures and is implemented in other jurisdictions, including connected vehicle technology for transit buses; demand-responsive transit, taxi and ridesharing services as options to meet system coverage goals in low-ridership areas of the city; and mobility-as-a-service advancements and successful implementations in medium-sized cities.