Comparing Different Transit Strategies to Tackle the Last Mile Issue in Low Demand Areas: A Case study: York Region Transit

by

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Author's declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Providing public transit service in low-density suburban areas is very challenging and inefficient because development patterns and transit demand do not support regular scheduled bus services while flexible and on-demand service is very expensive to provide. A further issue is that effective public transit is essential for providing equal access to opportunities for the residents of these areas. This is a controversial issue in most Canadian cities where they have difficulties in providing sustainable public transit.

Building upon the knowledge gained from an overview of the literature, this study aims at contributing to a better understanding of the crucial factors that influence the performance of public transit in low-density areas and develops a framework for evaluating different strategies for providing first/last mile transit service.

In order to accomplish this goal the literature of transit system performance measures as well as transit mode choice are reviewed and 7 major criteria are selected: safety & security, cost, time, flexibility, comfort, coverage, and availability of information. Secondly, a systematic literature review is conducted to identify different strategies that can be implemented as a last mile solution in low density areas. Employing the seven criteria in an evaluation framework, these possible strategies are explained and compared.

A case study using real data from York Region Transit (YRT) were utilized for comparing the two most common on-demand last mile strategies in the region. Results showed that outsourcing transit rides to instant ride-hailing companies –e.g. Uber- is financially beneficial to YRT and offers more coverage for potential riders, providing that reliability of their service is secured.

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List of abbreviations

CUTA	Canadian Urban Transit Association
DAR	Dial-A-Ride
GIS	Geographic Information System
GTA	Greater Toronto Area
GTHA	Greater Toronto and Hamilton Area
GTFS	General Transit Feed Specification
TTC	Toronto Transit Commission
YRT	York Region Transit
TCRP	Transit Cooperative Research Program
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled

1. Introduction

1.1. The importance of public transit

Transportation has a critical role in the development of any region and directly affects people's quality of life through the provision of access to jobs, entertainment, medical facilities and other needs. By providing access to opportunities, transportation systems affect the economic, environmental and social aspects of our lives.

Public transit, as one of the main parts of each cities' transportation system, has received considerable attention and funding for many years (Millar, 2012), most recently reflected in the $79 Billion that will be invested in Ontario's public transit over the next ten years (CUTA, 2018). However, the importance of public transit is not limited to economic development and facilitating the movement of people. Environmental and social issues are also addressed through public transit studies and investments. Particularly, energy consumption and CO2 emission (Beaudoin, Farzin, & Lin Lawell, 2015), as well as equity, accessibility, and mobility issues (Litman, 2014; Litman 2018). For example, based on Canadian Urban Transit Association Report (CUTA, 2010) public transit annually reduced the economic cost of traffic collisions by almost $2.5 billion, saved $115 million in health care costs related to respiratory illness, and reduced 2.4 million tonnes of greenhouse gas emissions. Considering sustainable and low carbon mobility, transportation policies tend to shift people from private car use to public transit (Miller, De Barros, Kattan, & Wirasinghe, 2016).

Increasing public transit ridership would benefit society as a whole, even those who may never board a public transit train or bus. In urban areas, shifting from private vehicles to public transit reduces congestion on the roads (Kramer, 2018). Even in rural and small urban areas, where congestion is not an issue, studies showed that increasing transit ridership had a considerable effect on the cost-benefit ratio for service providers, consequently supported the expansion of their services (Godavarthy, Mattson, & Ndembe, 2015).

Moreover, from a social equity perspective, public transit is a powerful means to ensure opportunities are accessible to all member of society, therefore, transit accessibility is critical for disadvantaged people. In this context, transit accessibility or transit access refers to the ease, in terms of proximity in distance or time, with which residents and workers can reach transit facilities (Manout, Bonnel, & Bouzouina, 2018). There are many people who do not have access to a private vehicle and their mobility is highly dependent on the availability of public transit. These captive riders are highly dependent on public transportation for their daily activities such as access to a job, shopping, entertainment, and social interactions. For them, public transit provides access to opportunities which otherwise might not be affordable to have. Among transit users, there are several choice riders who have access to a private vehicle but choose to use public transit for several reasons including its economic and environmental benefit. Attracting these group is also important for urban planners due to various benefits including economic and environmental betterment.

Considering all the benefits of a well-developed public transit system, it is important to know the current situation of public transit in our community to find opportunities for improvement. The following section offers some examples of studies that evaluated Canadian cities' public transit and compared them to other North American cities.

1.2. Public Transit in Canada

There are many studies that compare public transit among different cities, however, to be more accurate the following examples were selected from recent studies that include North American cities, as they have similarities in urban structure and cultural aspects of their residents toward transportation.

Concerning the commuting time on transit, a comparative study ranked 74 cities around the world based on online data collected from 250 million transit users worldwide. The best Canadian city was Vancouver, ranked 33, while Minneapolis St Paul, in the USA, was the best North American city which was ranked 20. The first 19 cities were all from European countries. Ottawa, Montreal, and Toronto were ranked 38, 46, and 69 respectively (Julliard, 2018).

Regarding the general access to public transit, in another multinational study, the number of residents who lived within a short walking distance (one kilometer) to rapid transit were compared across 25 major cities and their greater metro regions. Compared to European and Asian cities, North Americans had considerably lower accessibility to rapid transit. For example, in the city of Vancouver, 40% of residents lived in a walking distance to rapid transit while this number dropped to 19% for the metropolitan area of Vancouver. For Paris, these numbers were 100% and 50% respectively (Marks, 2016).

Particularly, in case of Toronto, based on data from 1996-2006, building new transit infrastructure did not necessarily attract more transit commuters but it did increase the accessibility by transit and augmented the transit mode share (Foth, Manaugh, & El-Geneidy, 2014). Another study pointed out that North American buses, subways, and light rail lines usually have lower ridership levels, fewer service hours, and longer waits between trains and buses than those in virtually every comparably wealthy European and Asian city (Currie, Delbosc, & Forbes, 2012).

Based on 2016 census report, in Canada, 12.4% of people who commute to work used public transit; this number was between 20-24% in city centers like Toronto, Montreal and Vancouver, around 14% in cities like Calgary and Winnipeg, and less than 10% in small cities such as London and Hamilton (Statistics Canada, 2018). A closer look at the ridership statistics of GTHA reveals that public transit mode share was significantly higher in high-density areas and central business districts – e.g. city of Toronto- compared to the surrounding cities which mostly consist of low-density suburban areas (Table 1). This difference partially is a result of the typical development patterns of North American suburban communities which are not transit-supportive (Kuzmyak, Pratt, Douglas, 2003).

As mentioned in this section, public transit has a low share in Canadian cities' transportation. This share even become less in suburban areas, and consequently we can see lower accessibility to transit in low-density areas and their residents have less access to opportunities.

Table 1 – Mode share for commuting in GTHA

	Driver %	Passenger %	Transit %	Go train %	Walk & Cycle %	Other %
City of Toronto	46	11	27	1	13	2
York Region	70	15	6	2	5	3
Peel Region	67	14	8	2	6	3
Durham Region	72	14	3	3	5	3
Halton Region	73	13	2	3	6	3
Hamilton	68	14	7	1	7	3

Source: Statistics Canada (2018)

1.3. Problem statement and research question

Increasing transit accessibility is important to support people who have no or limited access to private vehicles because otherwise, it leads to the isolation of these people who are most in need of affordable means of transport (Kramer & Goldstein, 2015). Many people live in low-density suburban areas as a location of affordable housing. For them, access to employment, entertainment, and other activities cost more due to the lack of public transit (Hess, 2005; Lucas, 2012). In most cases, there may be at least one main high-frequency transit line in the area, however, the connecting transit services have very low frequency and are often not in walking distance for many residents.

Connecting residents of these areas to the nearest high-frequency public transit service is a key issue which has been studied as a part of the first/last mile (also called last-mile) subject in public transit planning for many years (Boarnet, Giuliano, Hou, & Shin, 2017). Generally, the last-mile literature is about how people reach from their origins to the closest high-frequency transit station or egress station to reach their destination. This issue has been documented for a long time as a critical factor affecting transit use as it has an important impact on the people's decision to use transit for the entire trip (Hickman & Vecia, 2016). Transit feeders play an important role in this regard. They connect people to main transit lines and can enhance passenger's experience in three ways: minimizing passenger’s wait time, riding time and walking distance (D. Zhang et al, 2017).

Low-density areas on the fringe of the built urban environment often have scattered and low demand for public transit, and consequently, receive low-frequency service with very long cycles which discourage ridership. This negative loop leads to the higher cost of public transit service and lower service span in low-density areas (Nourbakhsh, 2014). The last-mile problem is a key barrier to better public transit utilization, meaning that the lack of dedicated last-mile solutions that are cost and time-efficient, significantly influence people’s experience with transit service (Tilahun, Thakuriah, Li, & Keita, 2016).

The discussion above highlights the significance of the need for successful last mile solutions. With the goal of increasing access to public transit in low-density areas, this research is formed to answer the following questions:

1. Which factors have the most influence on the performance of public transit service?
2. What are the options for providing public transit service in low-density areas?
3. Which option could be more efficient for the case study (York Region Transit)?

1.4. Framework of this study

The structure of this thesis moves on from this introduction to present the literature review in chapter two that focuses on three major subjects:

- major factors influencing transit performance from providers perspective
- major factors affecting transit ridership (travel mode choice)
- different options for last-mile transit service in low-density areas

Based on the finding of previous literature a methodology for evaluating different last-mile options is described in chapter three. In chapter four, the York Region Transit (YRT) system is studied in detail and options for last mile transit service in this region are compared using the framework development based on the literature. York is one of the regions that has low-performance transit service and has a scattered low-density development in many parts of the region. Considering that YRT already uses different strategies, it has been selected as a case study for this research.

2. Literature Review

In order to define a multi-dimensional framework to assess transit service performance, research should incorporate perspectives of the different stakeholders of public transit services - i.e. users and service providers (Hassan et al., 2013). Therefore, the narrative literature review in this study focuses on two main areas: First, agency reports, government plans, and academic literature that evaluate the performance of transit systems mostly from an economic perspective - e.g. cost efficiency and energy consumption. Second, surveys and academic literature that focus on common criteria that people use to decide whether to use transit or not. These are commonly referred to as modal choice in transit literature, which talks about the factors influencing transportation modes that people use for their daily activities.

This review describes how transit performance has been evaluated since the 1950s. The review also looks across different groups and their transportation mode choice. Eventually, some indicators will be selected to evaluate last mile solutions for low density areas, taking into considerations the availability of data.

2.1. Transit performance indicators

To ensure the quality of service, transit service providers need to assess the performances of their service based on efficiency and effectiveness measures. Efficiency is about how well a service is provided, while effectiveness is about how well demand is met, given the existing resources (Daraio et al., 2014). Although performance evaluation includes monitoring, evaluating economic performance, administering the organization, communicating the organization’s achievements and challenges, developing service design standards and noting community benefits (Transportation Research Board, 2003), in this research I have focused on economic indicators.

First part of this chapter reviews most common performance measures. Transit performance measurement literature shows that transit ridership and cost for providing transit service are the main factors in most performance indicators.

Considering that transit ridership is the result of potential user's decision-making about transportation mode they take, factors affecting their decision are explored in second part of this literature review.

The last part is dedicated to identifying different strategies that can be used as a last mile solution in low-density areas to increase transit ridership. In the literature, these concepts are also referred to as optimizing feeders to the transit network system in low-demand areas.

For the purpose of this study, I reviewed different transit system as well as travel modes that can be used in low-density areas. Then I studied the nature of each strategy to understand if it can be used as the last mile option in low-density areas. Hereof, I explored the literature to see whether these options have ever been used in a similar context. Besides, I looked for literature that compared the pros and cons of each option and more importantly transit networks which already used a combination of these options. Academic research and transit agency reports that compared these options in a real-world case study were reviewed and categorized to construct a systematic literature review for each strategy.

There is an extensive literature on measuring transit performance. The U.S. National Committee on Urban Transportation (1958) published a comprehensive report series that formed the base of measurement techniques for public transit. Since then many studies were conducted to evaluate those indicators and introduce new ones. Some of the most cited studies will be introduced in this chapter.

One of the most cited studies in this field is "Performance indicators for transit management" by Fielding and his colleagues that categorized the indicators into three groups, namely: efficiency, effectiveness, and overall indicators (Fielding, Gordon, Glauthier, & Lava, 1978). Fielding and his coworkers continued their work in several more studies and used U.S. transit data to test them (Chu, Fielding, & Lamar, 1992; Fielding, Babitsky, & Banner, 1985).

Subsequent to these efforts, many authors used similar indicators to analyze transit performance, knowing that no single indicator can reveal the relative or absolute performance of a transit system. In most cases, researchers who developed a framework for the analysis of public transit system's productivity separated measures of efficiency from measures of effectiveness (quality) for achieving ridership (Orth, Weidmann, & Dorbritz, 2012). Some studies showed that efficiency and effectiveness are positively correlated (Karlaftis, 2004) while others found a negative correlation between them (Chu et al., 1992). Despite that, in many cases, the terms of “performance”, “efficiency”, and “effectiveness” are still being used as synonyms.

One of the best and most comprehensive guidebooks for developing a transit performance measurement system was published by the Transit Cooperative Research Program –TCRP- (Transportation Research Board, 2003). This volume suggests that every transit system should be evaluated considering four points of view: customers, community, agency, and drivers. Also, steps and tools for creating a performance measurement program were discussed and several successful cities that incorporated these measures were introduced. These examples were selected from small and large cities all around the world, including Livermore in California, New York, and Sydney, Australia. According to this guidebook, a performance measurement system should be acceptable for stakeholder, flexible, reliable and linked to community goals. More than that, there should be a variety of measures with the relevant level of details that could be integrated into the agency’s decision making process.

Another comprehensive publication was conducted by Litman (2017) with the support of the Victoria Transport Policy Institute. He prepared a guidebook of best practice in public transit that compiled several indicators to evaluate the benefits and costs of the transit service based on the agency’s goal. Table 2 summarizes the measures and indicators he suggested to evaluate the economic performance of public transit.

In the Canadian context, as transportation is a shared responsibility among the federal, provincial, and municipal level of government, all these entities are participating in transit-related decision making. The federal government has the constitutional authority to oversee international and inter-provincial transportation including public transit that may cross provincial boundaries, while the provincial governments are responsible for intra-provincial plans. Each province sets its own standard and makes plans accordingly.

Table 2 - Measures of the economic performance of public transit

Goal	Indicators	Measures
Utilization (How well transit service and resources are utilized)	How many passengers are carried	Ridership
	The distance traveled by passengers on transit	Passenger-miles traveled
	How much of the fleet is used to provide service each day	Capital resource utilization Peak-to-base ratio
	How efficiently employees are utilized	Human resource utilization
	The amount of energy used by transit vehicles	Energy consumption
Efficiency (How well service is provided)	How much it costs to provide a given amount of service	Cost efficiency
	The amount of time vehicles travel empty	Service miles per revenue miles
	The number of vehicles used to serve the community	Population served per vehicles in max. service Service area per vehicles in max. service Capital resource utilization Performance ratio
	The amount of the fleet used to provide only peak service	Peak-to-base ratio
	The amount of energy used by transit vehicles	Energy consumption
Effectiveness (How well demand is met, given existing resources)	How much it costs to meet a given demand for transit services	Cost-effectiveness
	The number of passengers carried per hour	Productivity Mobility index
	The number of passengers carried, within the constraints of existing resources	Service effectiveness Performance ratio

Source: Litman (2017)

For example, in 2006, the Province of Ontario created the Greater Toronto Transportation Authority (today is known as Metrolinx) to deliver long-term sustainable transportation and better transit for the Greater Toronto and Hamilton Area (GTHA). Then, Metrolinx issued The Big Move (Greater Toronto Transportation Authority, 2008), a regional transportation plan to integrate transportation network throughout the GTHA. The most recent regional plan is the final draft of the Regional Transportation Plan (RTP 2041) released in 2018. Public transit provision is always one of the most important components of these plans.

According to the RTP 2041, strategies and actions receive priority based on their ability to grow transit ridership and increase accessibility to jobs. In order to increase accessibility to jobs, providing 24-hour transit service is becoming more important as the regional economy grows more diversified and part-time and contract employment becomes more prevalent.

The Big Move used several key performance indicators to assess transit initiatives. Regarding the evaluation of transit performance in low-density areas, these indicators include:

- Transit service per capita (annual total transit vehicle hours - excluding Go Transit - per capita)
- Living close to rapid transit (Percent of GTHA population living within 2 Km of regional rapid transit.)
- Transportation choice for individuals in low-income households (Transportation mode share for the commute to work of working individuals over 15 years age residing in a low-income household)
- Accessibility of transit (Portion of GTHA transit fleet vehicle that is accessible to people with limited mobility due to disability)
- Transportation choice for children (transportation mode share for all children aged 12-16 for the trip to school)
- Transportation choice for seniors (Transportation mode share for all seniors aged 65+)
- Road safety (Annual road-based accident fatalities in the GTHA & road-based accident injuries in the GTHA)

- Air quality (Average number of smog advisory days issued across the GTHA annually)
- Emissions (Annual per capita emissions of CO_2 from personal transportation sources)
- Transit between urban centers (Number of urban centers reachable within 45 minutes by transit)
- Transit efficiency (inflation-adjusted operating cost per passenger)

The required data are mostly captured from Statistics Canada Census Survey and Transportation Tomorrow Survey, Environmental Canada reports, and the transit schedules for each transit agency.

Usually, in low-density areas, demand for transit service is low and financial consideration forces transit providers to limit the service and create a negative cycle between demand and supply which leads to eliminating the service. This elimination effects those who need to access public transit. As we can see from all transit provider perspectives, transit ridership is the most important indicator associated with the success of the system. Consequently, mode choice literature becomes important as they study how to attract more riders.

2.2. Factors affecting potential riders' travel mode choice

There are numerous drawbacks and challenges in providing any type of transit service. The important question in reviewing previous experience is how effective these options have been. To compare the options, we need some criteria to measure. But before that, we need to enhance our understanding of the underlying dynamics of how people perceive and use transportation. In other words, to efficiently manage a transport network, it is important to understand how the traveling population makes their travel mode choices, just as much as the operating characteristics of the network itself.

There are different categorizations for factors affecting transit ridership. One of the review studies that broadly covered factors influencing mode choice is presented by Zhou (2012). He divided these factors into six groups:

Group 1: Physical environment and urban form factors such as population density, land use mixture, topography, availability of infrastructure, and multimodal network's connectivity.

Group 2: Mode-specific factors such as availability, access, convenience, comfort, privacy, freedom, safety, travel time and cost.

Group 3: Trip-makers' personal attributes such as occupation, marriage status, gender, age, income, daycare responsibilities, car ownership and possession of a driver's license.

Group 4: Trip characteristics such as time of travel, trip purpose, trip distance, trip origin, and destination.

Group 5: Presence of Travel Demand Management (TDM) measures such as parking cost or restriction information campaigns against car usage and transit pass subsidy.

Group 6: Psychological factors such as habit, attitude, concerns over health and the environment, familiarity with alternative modes of driving, and unconscious attachment to car usage.

A recent North American study examined the determinants of public transport ridership from 2002 to 2015 for 25 transit authorities across Canada and the United States (Boisjoly et al., 2018). They offered two different systems of categorization:

1. Micro-level vs. macro level.
2. External factors vs. internal factors

At the Micro level, the focus is on the aspects of individual decision making, while at the macro level, the larger region as a whole was studied. Within macro-level determinants, some are considered as internal and some as external factors. Internal factors relate entirely to decisions, policies, and conditions determined by the transit agency or the municipalities providing subsidies. Whilst external factors typically equate to wider economic influences affecting society at large, such as unemployment rates and gas prices (Boisjoly et al., 2018).

On macro level, factors such as population size and gas price (Jung, 2016; Lane, 2012; Mowak & Savage, 2013) received a considerable attention in scholar work while other factors such as weather condition (Kashfi, Bunker, & Yigitcanlar, 2015; Singhal, Kamga, & Yazici, 2014) and employment rate were less studied.

On the macro level, [2003, 2009, & 2013] Taylor and Fink and their colleagues published several papers. They have tested data on 265 urbanized areas on dozens of variables that measure transit system characteristics as well as regional geography, metropolitan economy, population characteristics, and auto/highway system characteristics. They found that controlling for the size of urban area, transit fare and service frequency impacted greatly on transit ridership; while increasing public subsidy of transit service had little effect on overall ridership (Taylor & Fink, 2003; Taylor, Miller, Iseki, & Fink, 2009; Taylor & Fink, 2013). In another study, Iseki and Ali (2015) have found a similar result. They have studied that effect of gasoline price, transit fare, service supply, and service frequency on transit ridership in 10 US urbanized areas.

At the micro level, transit planning requires a better understanding of individual decision-making and what drives the choice of transportation mode, particularly the motives behind the preference for a private car or public transport (Chakrabarti, 2017). There are different approaches in transit mode choice literature. Some studies are dedicated to how specific group of people (e.g. university students (Zhou, 2012), working parents (Murtagh, Gatersleben, & Uzzell, 2012), families with young children (McCarthy, Delbosc, Currie, & Molloy, 2017), or seniors (Shaheen, Allen, & Liu, 2008)) decides about transportation mode. Some studies specifically focused on one trip purpose (e.g. leisure (Collings, 1974) or work commute (Chakrabarti, 2017)). Some of them were focused on the specific part of the transit trip, like factors that contribute to the last mile problem (Tilahun et al., 2016), and more specifically, factors Influencing the decision to drive or walk short distances to public transport facilities (Walton & Sunseri, 2010).

Considering the focus of this study on the last mile issue, from several determinants of transit ridership the following items are selected to create an evaluation framework for last mile transit options:

2.2.1. Safety, and Security

When choosing a transportation mode, safety and security are the most important factors for every human being (Ganapati & Reddick, 2018), but statistics show that the level of safety is not similar in different modes of travel. Among the vehicles involved in fatal or injury collisions, passenger cars have the highest number, and bus and school vehicles have the lowest (Road Safety Research Office, 2017).

Although there is no comparison of security level among different modes of transportation, for some group of people like seniors (Luiu, Tight, & Burrow, 2018), families with young children (McLaren, 2016) and generally for women (Stark & Meschik, 2018) the security aspect of a transportation mode have more importance as they are more vulnerable to crimes.

2.2.2. Cost

Several empirical studies prove that increasing transit fare has a negative effect on transit ridership (Mattson, 2017). However, studies are not unanimous about how important it is compared to other factors. Some studies showed that travel cost and time are of lower importance to mode switching behavior than behavioral factors (e.g. habit formation towards car driving) and other transit service design attributes (e.g. crowding level, number of transfers, and schedule delays) (Idris, Nurul Habib, & Shalaby, 2015; Neoh, Chipulu, & Marshall, 2017); while others claimed that cost has the most effect on travel mode choice (Chakrabarti, 2017; Frei, Hyland & Mahmassani, 2017). It should be noted that it is not just transit fare or gas price, rather time and comfort are also tied to cost (Wilson, 2016).

2.2.3. Time

In Canadian cities, particularly low-density areas, travel time is one of the most important factors for people when deciding about transportation mode (Idris et al., 2015). Time is an asset which people value differently. How much value they put on their time has a direct impact on their tolerance for how much time they are willing to spend on transportation and what mode they choose, in other words, how much they are willing to pay to save time, and have flexibility and comfort (Kim, Moon, Kim, 2017; Yu, Lu, Pan, & Guo, 2017). In this regard, many scholars found that time-related factors (such as frequency of service, travel time, and waiting time) strongly affect travel mode choice and eventually transit ridership (Lopez-Saez, 2016; Ma, Yang, Ding, Liu, Zhu, 2018; Vande

Walle & Steenberghen, 2004). They also found that providing more days of service had a positive effect on transit ridership (Mattson, 2017).

In order to minimize travel time, connecting bus schedules are very important for infrequent services, i.e. feeder buses (Dou, Gong, Guo, & Tao, 2017). Different mathematical methods have been used to optimize bus scheduling (Catala, 2011; Sengupta & Gupta, 1980), still many buses are missed by few minutes and people sometimes have to wait a long time for the next service as it is impossible to account all factors influencing a trip time.

2.2.4. Flexibility

Flexibility is one of the main reasons people decide to use their own car or take a taxi instead of sharing the ride or using public transit (Tischer & Dobson, 1979; Vande Walle & Steenberghen, 2004; Yu et al., 2017). Flexibility, like some other factors, has two aspects: time and place. This means taking people to where they want to go, whenever they want to; which tie the concept of flexibility to the coverage and comfort (Ritter, 2014).

2.2.5. Comfort

Many people choose to use a private car because it gives them more physical comfort (Tischer & Dobson, 1979). Aside from the flexibility of time and being available at the doorstep, availability of seating is an important aspect of physical comfort. The ease of payment and availability of information could affect people decision (Siuhi & Mwakalonge, 2016) as well.

Currently, almost all transit providers included easy payment options such as card tab into their fare payment option, mobile payment is also expected to widely be applied in transit services (Ganapati & Reddick, 2018). Chicago, New York, and San Francisco already added this method to their payment options (Hernandez, 2011).

2.2.6. Coverage

Considering the focus of this research, among factors influencing transit ridership, transit service coverage is the most relevant measure to the last mile issue. The importance of access to transit has been mentioned in several empirical studies (Jiang, 2017; Limanond & Neimeier, 2003). Although in literature, the spatial coverage (also called accessibility) received more attention than time coverage (i.e. a time span that transit service is available and the frequency of service) (Mamun, Lownes, Osleeb, & Bertolaccini, 2013).

The tendency to use public transit deteriorates with distance from the transit stop or station, regardless of the transit mode and regardless of the access mode. However, as the quality of the transit service increases, so does the distance people are willing to walk to access the transit service. Meaning that the catchment area of bus service is less than rail service. Also, when people have the option to use bicycle or car parking lot near a transit stop, they are more likely to use transit service, and the catchment area of transit service expands (Vuchic, 2005).

In the simplest form, a circle of 400m diameter (that usually, a person walks for 10 minutes) is used as a coverage area of a bus stop, although individuals' walking speed and maximum tolerant walking distance are different (Olszewski & Wibowo, 2005). Moreover, studies showed that other factors, such as weather condition, parking charges, carriage of goods (Walton & Sunseri, 2010) and even individual's social identity (Murtagh et al., 2012) affect people's perception about distance and accessibility of public transit network.

2.2.7. Availability of information

A person's transit experience starts before they step onto the bus or train; it starts the moment they leave their house, office or any other starting point. Likewise, it doesn't necessarily end the moment they step off the bus or train. Rather it ends at their final destination. Among other factors, the success of a public transit system relies heavily on how easily people can reach the transit station (Locquiao, 2016).

Real-time information plays an important role in travel timing. As part of this section, I have listed some of the relevant studies in Table 3. These studies are indicating that just by providing real-time information, transit systems might achieve the goal of increasing transit ridership. This can be even more successful if combined with facilitating programs that enhance commuters' opportunities to be exposed to real-time information before using the transit system (Tang & Thakuriah, 2011). Having real-time information will shorten waiting time at the stop and consequently overall travel time, and will provide a positive travel experience to passengers (Ferris, Watkins, & Borning, 2010; Fonzone, 2015).

Table 3 - Real-time information influencing transit ridership

Author	Publication year	Title
Taylor & Fink	2003	The Factors Influencing Transit Ridership: A Review and Analysis of Ridership Literature
Collin et al	2007	txt bus: Wait time information on demand
Tang & Thakuriah	2011	Will psychological effects of real-time transit information systems lead to ridership gain?
Thakuriah, Tang, Vassilakis	2011	Spatio-temporal effects of bus arrival time information
Tang, Ross, Han	2012	Substitution or complementary? effect of bus tracker system on ridership
Sun et al	2013	The analysis of behavioral responses to transit information
Rahman, Wirasinghe, Kattan	2013	Users' views on current and future real-time bus information systems
Poon & stopher	2014	Investigating the effects of different types of travel information on travelers' learning in a public transport setting using an experimental approach
Wang & Wu	2015	Effects of real-time transit information services on the patronage behavior of passengers
Brakewood, Macfarlane & Watkins	2015	The impact of real-time information on bus ridership in New York City
Fonzone	2015	What do you do with your app? Study of bus rider decision making with real-time passenger information
locquiao	2016	Multifaceted analysis of transit station accessibility characteristics based on First Mile Last Mile
Ge et al	2017	Effects of a public real-time multi-modal transportation information display on travel behavior and attitudes

2.3. How transit systems tackle the problem of the last mile

A systematic literature search for peer-reviewed publications was conducted, focusing on different options providing the last mile public transportation service in low-density areas. The results show there are several studies that compare different options for traveling between trip origin and closest high-frequency transit station/stop particularly for suburban areas. Several others were focused on one strategy and evaluated them based on a few criteria. And a few studies compared two or more options for the last mile service.

As Table 4 shows, three databases were used: Prima, Scopus, and Web of Science. Google Scholar was ignored because it offers thousands of results that are hard to narrow down. Combinations of various search terms were explored within titles, keywords, subject, and abstracts to identify relevant studies. Search terms include “public transportation”, “transit”, “last mile”, “low density”, “transit stop access”, “On-demand”, and “demand responsive”. Table 4 also shows the number of hits for each combination. Results then refined based on categories, those related to transportation, urban studies, and environmental studies and management are selected.

Moreover, the archive of the Transit Cooperative Research Program (TCRP), Victoria Transportation Policy Institute and Transportation Research Record for the past 10 years was searched to find the related materials. The references in the identified articles were also reviewed to locate additional studies for consideration.

Table 4- Search terms and number of results

Search terms	Search engine	Number of hits		
		Articles	Dissertation	Others
“Last mile” & “transit”	Prima	14	1	1
	Scopus	32		38
	Web of science	32		21
“Last mile” & “Public transportation”	Prima	3	2	
	Scopus	12		21
	Web of science	7		12
“low density” & “transit”	Prima	25		1
	Scopus	423		77
	Web of science	298		39
“on-demand” & “transit”	Prima	872	22	179
	Scopus	122		116
	Web of science	84		63
“low density” & “Public transportation”	Prima	3		4
	Scopus	20		11
	Web of science	10		6
“Demand responsive” & “transit”	Prima	42	9	10
	Scopus	135		72
	Web of science	101		41

After deleting duplicates and irrelevant studies, the initial results included 679 articles, 23 dissertations, 15 technical reports, 136 consisting of books, conference proceeding, newspaper reports and other forms of publications. Among those, only articles, technical reports, and dissertation were selected for review of their abstracts. The following study characteristics were extracted from each study: first author, publication year, study location and setting, and main contributions. Then studies were categorized based on the kind of solution they provided. The concept of last mile service is also present in articles dealing with freight transportation. However, due to the different nature of services and key characteristics these literature were excluded from this systematic review.

All of the strategies mentioned in any of these literatures are individually discussed in the following sections. Pros and cons, limitations and opportunities for each option are explained based on the evaluation framework from the literature review.

2.3.1. Promote bicycle use

To improve first/last mile access to and from transit, bicycle use is an affordable and healthy alternative to a long distance walking trip or a short distance bus trip (Makarova, Pashkevich, Shubenkova, & Mukhametdinov, 2017). Studies showed that facilitating bicycle use to access transit stations/stops not only expands the transit catchment area compared to pedestrian-transit catchment area (Zuo, Wei, & Rohne, 2018) but it also has economic advantages for the city; the cost of a bike rack is approximately $100 for parking a bike, in contrast to $30000-40,000 for a parking spot for a car (Bachand-Marleau, 2011). In order to encourage using a personal bicycle to access transit stations, transit agencies have placed bicycle racks on the fronts of buses so cyclists can take their bike with them when they use the bus (Li & Joh, 2017).

Besides promoting the use of personal bicycle, in recent years the concept of the sharing economy has introduced “bike shares” as part of the last mile solution for many cities. Many studies (Table 5) claim that shared bicycles were successful in attracting more people and reducing travel times with an environmentally friendly solution.

Table 5 – Studies that covered bike-sharing and public transit

Author	Publication year	Title
Bachand-marleau, Larsen, El-Geneidy	2010	The much-anticipated marriage of cycling and transit: examining bicycle sharing system in Montreal
Dong, Dong, Wang	2011	Low Carbon transport, under the name of people: the confusion of last mile problem and its solutions
Zhang & Huang	2012	Performance evaluation of bike sharing system
Kaiser	2012	Closing the gap: bike shares help complete the ' last mile' in the right conditions, bike-share programs can help mobilize a city
Liu, Jia, Cheng	2012	Solving the Last Mile Problem: Ensure the Success of Public Bicycle System
petrie	2013	The green mile: innovations push first and last mile travel modes into a new era to allow for better access to transit.(MULTI MODES)
Zhang et al	2013	evaluation of public bicycle system service quality based on revised SERVQUAL
Wilhelm et al	2015	Auto-bikes: autonomous electric bicycles for first and last mile mobility on demand
Ma, Liu, & Erdogan	2015	Bicycle Sharing and Public Transit
Villwock-witte	2015	Case Study of Transit- Bicycle Integration Openbaar Vervoer-fiets
Ram et al	2016	Smart-bike: policy making and decision support for bike share systems
Fuentes et al	2017	Feasibility study of a building-integrated PV manager to power a last mile electric vehicle sharing system (e-bike sharing)
Chen et al	2017	service evaluation of public bicycle scheme from a user perspective: an
Lu et al	2017	observations of public bikesharing: experiences from Ningbo, China
Lowalekar et al	2017	Online repositioning in bike sharing systems

Table 5 continued – Studies that covered bike-sharing and public transit

Author	Publication year	Title
Ghanem, Elhenawy, Almannaa, ashqar, rakha	2017	Bike share travel time modeling
Liu, Wu, zhou	2018	Public bicycle system ridership modes based on CNL Model
Ma et al	2018	Understanding bikeshare mode as a feeder to metro by isolating metrobikeshare transfers from smart card data
Van Goeverden & Correia	2018	potential of peer to peer bike sharing for relieving bike parking capacity shortage at train stations
Adnan et al	2018	Last mile travel and bicycle sharing system in small/medium sized cities
Campbell et al	2016	factors influencing the choice of shared bicycles and shared electric bikes in Beijing
Munoz-Mendez, et al	2018	Community structures, interactions and dynamics in London's bicycle sharing network
chang et al	2018	Innovative bike-sharing in china: solving faulty bike-sharing recycling problem
Ren et al	2018	Research on public bicycle shuttle demands in urban rail transit station
Jasinki	2018	Sharing the E-Scooters. investments in bicycle and scooter sharing services

However, bike share is usually an affordable last mile solution for downtown cores as riders should return the bikes typically between 30-45 minutes to a bike station which may not be practical in low-density suburbs (Dong, Dong, & Wang, 2011). Moreover using a bicycle or walking long distances to a transit stop is not an option for most people regardless of their health condition (Zuo et al., 2018). Even a healthy young rider cannot use a bicycle in rainy, cold Canadian winter or when they carry several shopping bags. Therefore this strategy cannot be a viable option for increasing transit accessibility in Canadian low-density areas.

2.3.2. Facilitate using personal vehicle

In order to encourage people to use their own vehicle to reach transit stations (i.e. as a first/last mile option) Park-N-Ride facilities are located near transit hubs (often rail station). In a low-density area where these parking facilities are usually free, it is a common way for many people to travel the first/last mile of their trip (Olaru, Smith, Xia, & Lin, 2014). In an empirical study, Niles and Pogodzinski (2016) examined the effect of Park-and-Ride availability on bus transit productivity in five bus transit system in the western U.S. They found that the ridership per service hour was increased by providing Park-and-Ride facilities near major bus stops in suburban areas. However, Park-and-Ride facilities have some limitations considering the last mile issue:

- Many people who do not have access to private vehicles will be left behind. For these people, carpooling can be an option. Studies showed that instant carpool apps helped a lot in finding more opportunities in this regards (Bian & Liu, 2017; Masoud, Lloret-Batlle, & Jayakrishnan, 2017).
- Among those who have personal vehicles, this method only works if people are planning on a long distance trip by transit as opposed to a relatively short distance. For relatively shorter distances, transit fares compared to gas price and parking fees at the destination become important factors in choosing one method of transit over another. Therefore, a relatively short distance in a low-density area is often not considered via public transit (Nguyen, Chikaraishi, Fujiwara, & Zhang, 2017). Studies that found parking facilities generate more transit trip were mostly examined regional bus or rail services (Palakurthy, Tung, Cryer, & Bell, 2017).

2.3.3. Informal transit: jeepney, Jitney, dollar van …

Informal transit (e.g. Jipneeys, Jitneys, Dollar vans) is a very common mean of mobility in the developing world beside public transit. When informal transport offers an inexpensive, fast and flexible mode of transportation, it is considered as a last mile option (Cervero, 2017). Informal transit often equals unregulated on-street ride-hailing (Cervero & Golub, 2007). In many cases in Asia (Lindsay, 2016), Africa (Del Mistro & Behrens, 2015) and South America (Golub, 2003), authorities have tried to regulate the informal transit to minimize the conflict raised from competition and free market (Lindsay, 2016) and merge it to public transit (Schalekamp & Behrens, 2010).

By contrast, European and North American cities do not have effective models for such mobility services, and the regulatory frameworks generally form barriers to their introduction, although, in big cities like New York, many unauthorized informal transit providers are working (Goldwyn, 2017). Regarding Canadian urban area, there is neither a regulatory framework for informal transit to work nor interest from informal transit providers, because it does not cost effective in low-density areas (Stroup, 2015). More importantly, due to the lack of information about the driver, there are safety and security concerns, which is magnified in low-density suburbs with little surveillance mechanism (Cervero & Golub, 2007).

2.3.4. Demand responsive Transit

Demand Responsive Transport (DRT) systems is a general term for modified traditional fix-route fix-schedule bus service that has the flexibility to adjust with transit demand (Bruun, 2014). DRT can provide flexible services in hard to serve areas (due to demographic or street layout), low demand time periods, and even for an entire small city. In order to adjust service capacity to travel demand, the system can use different vehicles, run with a flexible schedule, and adjust the routes (Koffman, 2004).

DRT is not a new subject in transit planning. It has been well studied in Asia, European countries as well as in the North American context (Brake, Nelson, & Wright, 2004; Liu & Cedar, 2015; Mageean & Nelson, 2003). Arrillaga and Mouchahior (1974) prepared one of the earliest documented guidelines for demand responsive system planning for the USA, followed by an interpretive review by Higgins (1976). With a numerical analysis, Chang and Schonfeld (1991) proved that by combining flexible service and fix-routes bus service, the average system cost will decrease. For years DRT has been adopted in many transit organization and best practices were studied (Dessouky, Palmer, & Abdelmaguid, 2003). Among those, Koffman (2004) did one of the most cited comprehensive reports which documented more than 50 transit systems throughout North America that have experience with any kind of flexible transit services at that time and offered recommendation for future practices.

The trade-off between the alternative modes is basically determined by the level of demand that can accommodate (number of passengers per vehicle) and their flexibility (fixed route vs. flexible route). Quadrifoglio and Li (2009), among others, offered a methodology to derive the critical demand density for designing and operating feeder transit service. Moreover, there is a rich literature on DRT in Great Britain, in order to determine what type of services exist and to examine which are working well and why a particular DRT could be a sustainable local public transport system (Ryley, Stanley, Enoch, Zanni, & Quddus, 2014).

Since the introduction of DRT, many advanced technologies and management practices have been proposed and implemented to improve the efficiency of the service (Pashaie-Avval, 2001) but, evidence for the effectiveness of these actions has been based on projections or small pilot studies (Rahimi, Amirgholy, & Gonzales, 2018). Papanikolaou and her coworkers (2017) offered a methodological framework to assess the success of DRT services and examine the modeling and decision-making issues related to DRT. They divided previous research on DRT systems into two broad fields in terms of mathematical tools and methodological approaches:

- Research work on the strategic level which uses mainly econometric and economic modeling tools,
- Research work on the tactical and operational level which uses mainly operational research or tools and simulation techniques

Unfortunately, while attractive in principle, several barriers conspire to limit the effectiveness of such services in practice. These barriers include institutional frameworks such as policy and regulation; economic issues of funding and fares; operational issues of fleet and vehicles; operator and community attitudes; and information and education (Mulley, Nelson, Teal, Wright, & Daniels, 2012). The success of DRT is in tailoring the service to the context. One method could work well in a neighborhood but might not be a proper choice for another place based on demand distribution geographically and time-wise (Godavarthy et al.,2015). Following are the different ways that a public transit system can address low demand in some parts of transit service area:

Mix fleet

One way of adding flexibility to DRT is by using different sizes of vehicles based on demand. By using smaller vehicles to serve areas with lower demand, less fuel is consumed and lower wage drivers are employed, consequently, operational costs decreased and efficiency increased (Kim & Schonfeld, 2013).

Many studies presented methods of fleet selection, distribution and scheduling for better allocation of resources under different market conditions (Li, Sumalee, Li, & Lam, 2008; Mishra, Sharma, Mathew, & Khasnabis, 2013; Sengupta & Gupta, 1980). Their results showed this strategy could be effective in North American low-density suburbs that barely support a full bus because compared to informal transit, it is safer and more reliable while it cost less than ordinary bus services. Using a smaller fleet is efficient when the ridership is low but steady, like services for the low-density neighborhood on peak time of morning and evening when people go/return to work or school.

Semi-Flexible bus service: flexible stops and route, flexible time

Another solution for adding flexibility is to let people use the bus out of the original route or get on/off on a requested stop. This kind of services is referred to as semi or demi flexible transit service in the literature (Errico, Crainic, Malucelli, & Nonato, 2013). Travel times are estimated, but since the requests and trip insertions can change, it is not guaranteed. Depending on the structure of the service, users may need to spend more time planning and learning to use the system (for instance, understanding the locations where they are able to flag a vehicle, or that they need to request service at an optional stop in advance in order to activate it) (Qiu, Li, & Zhang, 2014). The requirements on the part of the user make it less intuitive than fixed route transit and perhaps more cumbersome than personal auto, making it difficult for such services to compete with private auto (Frei et al., 2017).

Koffman (2004) categorized these services into six main forms, including:

- Route deviation: Vehicles operate on a regular schedule along with a well-defined path, with or without marked bus stops, and deviate to serve demand-responsive requests within a zone around the path. The width or extent of the zone may be precisely established or flexible.

- Point deviation: Vehicles serve demand-responsive requests within a zone and also serve a limited number of stops within the zone without any regular path between the stops.
- Demand-responsive connector—Vehicles operate in a demand-responsive mode within a zone, with one or more scheduled transfer points that connect with a fixed-route network. A high percentage of ridership consists of trips to or from the transfer points.
- Request stops—Vehicles operate in conventional fixed-route, fixed-schedule mode and also serve a limited number of defined stops near the route in response to passenger requests. (Request stops differ from flag stops in not being directly on the route.)
- Flexible-route segments—Vehicles operate in conventional fixed-route, fixed-schedule mode, but switch to demand-responsive operation for a limited portion of the route.
- Zone route—Vehicles operate in demand-responsive mode along with a corridor with established departure and arrival times at one or more endpoints.

Figure 1 presents a demonstration of these forms.

Errico and his team (2013) provided another comprehensive literature review and framed a unifying model for representing and planning semi-flexible systems. Other scholars added strategies to improve the performance of these systems (Qiu et al., 2014); looked at operation policies (Qiu, Shen, Zhang, An, 2015), offered mathematical models to optimize flexible transit (Nourbakhsh, 2014; Pan et al., 2014), and test them with real-life case studies (Shen, Yang, Gao, & Qiu, 2017).

Coordination with regional fixed-route networks and with paratransit service is an important challenge of most flexible service. However, these methods are generally designed for areas that have non-homogeneous but high ridership within few clusters of a residence located close to the main line. Therefore, without too many deviations, those areas could also be served by buses nearby (Alshalalfah, 2009).

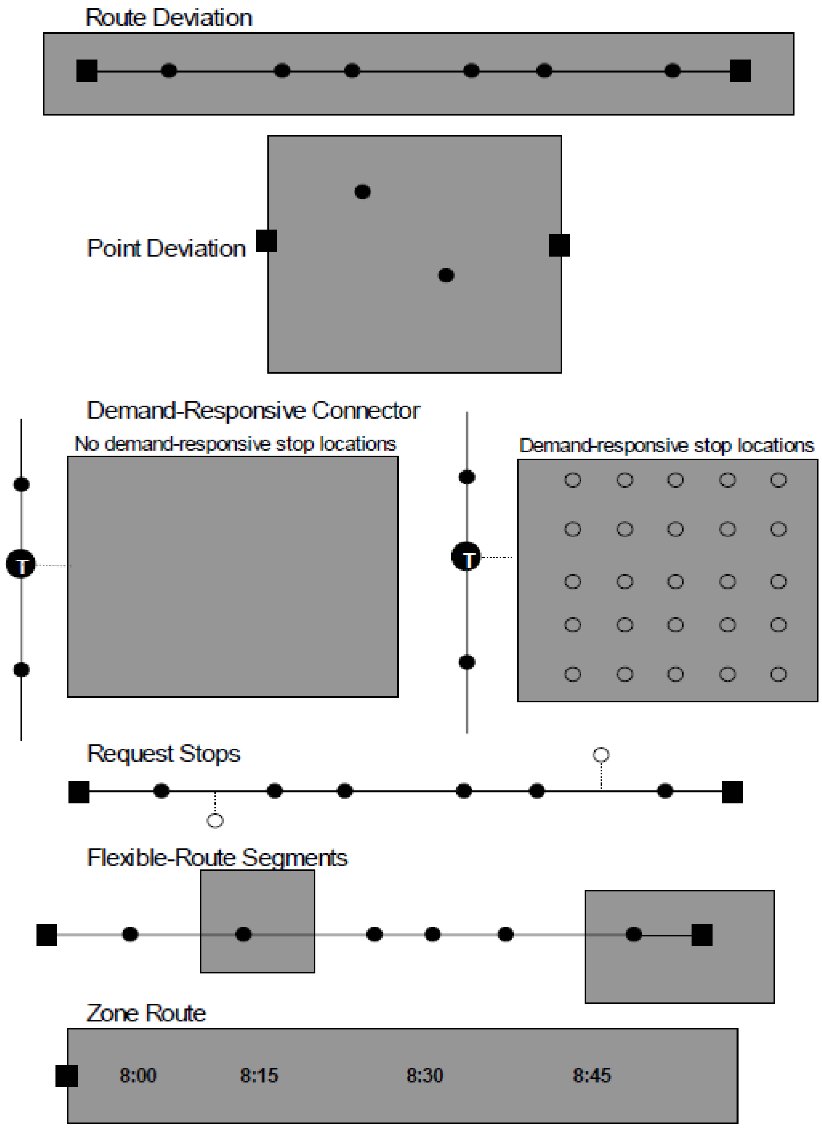

Figure 1 - Flexible service type

Source: Koffman (2004)

Dial-A-ride

Dial-A-Ride (DAR) have emerged to offer accessibility to mobility impaired individuals by using special fleets. Later, this service was expanded to the general public in low demand areas where this service integrated with timetabled fixed bus routes to expand access to transit (Posada, Andersson, & Hall, 2017).

Among transit networks that offer DAR, some have a dispatcher and required calling a dedicated number in advance – e.g. York region, Ontario, some use a real-time automated system - a website or an app – instead of a dispatcher and do not require advance reservations – e.g. California.

From the user perspective, these systems seem like taxis because they provide door-to-door service and are to some extent are on-demand (since they have time windows and limitations). From an operator perspective, providing curbside, door-to-door service is costly. They often limit DAR to pick up/drop off at the bus station or population centers, and zone-based services are rarely provided to the general public.

By combining the benefits of public transit and taxi-based services, DAR was supposed to deliver a relatively cheap yet comprehensive service (Cayford & Yim, 2004). In one of the earliest theoretical study for low-density areas, Ward (1975) compared two alternatives –i.e. fix-route vs. DAR- in a hypothetical service area for a range of assumed transit demand. As the efficiency indicators, he used passenger trips per vehicle hour, cost per passenger and travel time – including walking to the transit stop and waiting time. Based on his comparison, DAR can provide better service at all demand levels below 100 passengers per square mile per hour.

Following these studies, DAR becomes a popular service in low-density areas. However, in practice, the costs of such systems are high and the benefits are very mixed (Posada et al., 2017). Molenbruch, Braekers, & Cris (2017) prepared a thorough literature review on DAR problems. Based on their review, DAR services typically have not led to significant increases in demand or diverted many drivers from their cars, consequently, they didn’t have a significant impact on congestion or air pollution either.

With the introduction of Autonomous vehicles (AVs), their potential as an upgrade to conventional personal vehicles with the essential characteristics of demand responsiveness, fleet repositioning, and share-ability was recognized. Using AVs as a part of public transit is still in their early stages of predictions and assumptions. Recently, several researchers simulated shared AVs as an alternative to bus on low demand routes and to provide last mile service (Moorthy, De Kleine, Keoleian, Good, Lewis, 2017; Shen, Zhang, & Zhao, 2018; Vakayil, Gruel, & Samaranayake, 2017; Wen, Chen, Nassir, & Zhao, 2018).

They believe that the integrated system has the potential of enhancing service quality, occupying fewer road resources, being financially sustainable, and utilizing bus services more efficiently. However, these studies are hypothetical and based on simulations, in reality, the result might be different. Although some studies supported public acceptance of AVs as a part of transit fleet (Lu, Du, Dunham-Jones, Park, & Crittenden, 2017), these vehicles are still expensive and there are some unresolved safety concerns about them.

2.3.5. Outsourcing rides: Uber, Lyft, Taxicab

Contracting out a part of transit services to private taxi companies is not a new idea. Tidewater Transportation District Commission was one of the first transit agencies that used this method to lower the cost of providing transit service in low-density communities in Virginia (Talley & Anderson, 1986). Boston public transit, also, has incorporated non-dedicated vehicles, taxicabs, into their service models. By outsourcing a part of their service and allowing the fleet size to vary dynamically according to changes in demand, the operational costs have reduced (Austin & Zegras, 2012).

Now that dynamic ridesharing (also known as instant ride-hailing) platforms – Uber and Lyft for example - are rapidly replacing conventional taxicab services, several scholars have evaluated the possibility of integrating dynamic ridesharing service with public transit to solve the last mile issue (Chen & Nie, 2017; Kessler, 2017; Rahimi et al., 2018; Rayle, Dai, Chan, Cervero, & Shaheen, 2016; Shaheen & Chan, 2016; Yan, Levine, & Zhao, 2018). They believe that by replacing low-ridership bus lines with ridesourcing services, transit ridership will slightly increase, while operations costs will reduce. The service improvements offered by ridesourcing mainly come from reductions in wait time and in-vehicle time. Moreover, where evening and weekend bus service were outsourced, the transit agency was able to decrease the overtime pay of bus operators which result in operation cost reduction.

However, there is limited information and data about how these services may affect transportation decisions and travel patterns (Clewlow, 2016). While an integrated system of ridesourcing services and public transit is conceptually appealing, transit agencies need to anticipate how travelers will respond to it. So far there is only one study that surveyed the preference of riders about using ridesharing service as a part of transit service (Yan et al., 2018), although there are many studies that evaluated peoples' attitude regarding ridesharing service in general (Di Gianni, 2015; Rekhviashvili &

Sgibnev, 2018; Sarriera et al., 2017). In particular, Yen and their colleagues (Yan et al., 2018) found that transfers and additional pickups are major deterrents for users of this service.

In practice, Innisfil, Ontario is the first Canadian city that completely outsourced its public transit to Uber. Seattle's Expanded Mobility Portfolio is extended by adding UberHop (Lewis, 2017). The Charlotte Area Transit System (CATS) is in the process of developing a partnership model with ride-sourcing services to provide not only first-last mile connections, but also to expand its mobility offering. In Colorado, Lyft is working with the city of Centennial and Denver Regional Transportation District (RTD) on a pilot to provide residents and workers with free (grant-subsidized) Lyft rides to and from a suburban light rail station. RTD estimates that the passenger subsidies will cost less than the agency's current costs for its own on-demand bus operations. Uber provides the necessary connections to and from MARTA (Metropolitan Atlanta Rapid Transit Authority) rail stations and it provides service at times when transit is not operating as frequently. It is believed that ridesharing services, coupled with MARTA, can help their customers move about the city cost-effectively and conveniently (Uber, 2015).

Studies that compared different options

In this section, selected studies were described that focused on low-density areas and compared two or more options for providing transit service. As a result of my systematic literature review shows, in most cases, the comparison is between on-demand and conventional fixed route bus service. Only a few studies considered other options.

There are more studies that compared demand responsive transit with fixed route service, but those who used a case study for demonstrating their comparison were mentioned here. In many studies, although in the subject the term DRT was used, by that they were actually referring to DAR service.

Table 6 - List of comparative studies on last mile solutions

Author (year)	Strategies	Criteria
Ward (1975)	Fixed route & flexible route bus system	Operating cost & level of service
Talley and Anderson (1986)	Conventional bus, paratransit, and contracted-out services	Cost & management issues
Chang and Schonfeld (1991)	Fixed route & flexible route bus system	Operating cost
Johnson (2006)	Conventional bus, DAR, and taxi	Operating cost
Diana, Quadrifoglio, and Pronello (2009)	Fixed route and DAR	Travel distance
Nourbakhsh and Ouyang (2011)	Fixed route, flexible route, and taxi	System cost
Edwards and Watkins (2013)	Fixed route and DAR	Travel time & Operating Cost
Chandra, Bari, Devarasetty, and Vadali (2013)	Fixed route and DAR	Accessibility
Engel-Yan, Malvika, Livett, and Rebecca (2014)	Park-n-Ride, pedestrian and bus service	Accessibility
Godavarthy, Mattson, and Ndembe (2015)	Fixed route and DRT	Cost-benefit ratio
Qui, Li, and Haghani (2015)	Fixed route & flexible route bus system	Service quality
Fagnant, Kockelman, and Bansal (2015)	Shared Autonomous Vehicles and Conventional bus	Vehicle miles traveled
Moorthy, De Kleine, Keoleian, Good, and Lewis (2017)	Shared Autonomous Vehicles and Conventional bus	Environmental, cost, & performance metrics

Table 6 continued - List of comparative studies on last-mile solutions

Author (year)	Strategies	Criteria
Merlin (2017)	Automated shared-ride taxi transit and Conventional bus	Level of service, operational cost & carbon emission
Scheltes and Correia (2017)	Walking, cycling, and Shared Autonomous Vehicles	Travel time including waiting time
Rahimi, Amirgholy, and Gonzales (2018)	DRT and Ridesourcing	Operating cost
Navidi, Ronal, and Winter (2018)	Fixed route and DRT	Perceived travel time by passengers
Hoblik (2018)	Bike sharing, Taxi, and ridesourcing	Accessibility, time, cost
Zhang, Wang, and Meng (2018)	Park & Ride and DRT	Social welfare & cost
Shen, Zhang, and Zhao (2018)	Shared Autonomous Vehicles and Conventional bus	Service quality, road traffic, operating cost and revenue

As mentioned before, Talley and Anderson (1986) offered one of the earliest and most comprehensive comparisons that include several strategies. More importantly, their comparison was based on real data on a multi-service transit firm that already implemented three strategies. Not only they compared the operational cost of service but also talked about the managerial issues, such as labor management and scheduling. The result of this study showed that contracting out part of the transit service was a cost-efficient choice for improving service quality and reducing operating deficits.

Johnson (2006) offered a model for comparing conventional bus, taxi, and DAR systems for rural or low-density areas and introduced thresholds of demands beyond which different systems were preferable. He also assumed demand was fixed and uniformly distributed over the service area. His mathematical model included a different aspect of cost, including operator cost, waiting cost, access cost, etc.and he concluded that the taxi system has the least expensive total cost per trip.

The comparative study of Diana, Quadrifoglio, and Pronello (2009) was also based on a hypothetical mathematic model for cost and demand. Their main parameter for comparing DAR and fix bus service was the distance traveled by bus. They conclude that DAR performed better than fix bus service. Nourbakhsh and Ouyang (2011) performed a hypothetical mathematical analysis in a homogenously distributed demand over a square area. They confirmed that each system is advantageous under certain passenger demand levels. In the low-to-moderate demand level, their proposed flexible-route system had the lowest system cost compared to fix-route bus and taxi.

Edwards and Watkins (2013) used real passenger demand data from Atlanta city as an input for their model. They compared DAR and fixed-route bus service on average passenger travel time and operating cost for a range of travel demand (i.e. passenger per minute). They conclude DAR could provide a less expensive alternative for handling trip requests for stations with relatively low demand at off-peak hours. Chandra and her coworkers (2013) also offered a mathematical model to estimate and enhance the accessibility of transit feeder lines. They calibrated their model by several real case data from Denver flexible route services. They offered a formula to calculate the optimum number of passengers that should be ideally served in a given circle for DAR service.

Engel-Yan, Malvika, Livett, and Rebecca (2014) compared different strategies for providing last-mile access to transit stations, including Park-n-Ride. However, their focus was on commuter rail stations which have different criteria compared to bus service in low-demand areas. Godavarthy, Mattson, and Ndembe (2015) evaluated the real data from the U.S.A. at the national level. They compared the cost-benefit ratio for fixed route and DAR services in general. Transit benefits included a wide range of factors, including the value of that trip to the passenger considering the purpose of the trip, vehicle ownership and operation cost, emission cost saving and crash cost saving. For example, they believe that benefit-cost ratio becomes more than 3 to 1 if it is assumed that half of the trip would not be made in the absence of transit and to more than 4 to 1 if 30% of trips are for a medical purpose. They believe that DAR service provides significant benefits per trip, but the cost of providing this service is also significantly higher than fixed-route bus services.

Rahimi, Amirgholy, and Gonzales (2018) proposed a model to estimate the required resources to service the demand for DRT services. They calibrated their model based on data from New Jersey Transit service in 2012. Following that, they introduced efficiency metrics – e.g. fleet size, VHT, VMT, and agency cost- to identify where DRT system is not operating efficiently and too many resources are deployed. Consequently, they offered a complicated mathematical formula to establish a threshold for outsourcing rides to ridesharing companies using cost per trip and annual demand as indicators (Figure 2). Their formula basically says, wherever the cost of providing on-demand transit is less than the average ridesharing fare for that area, it is better to out-source the ride to ridesharing companies.

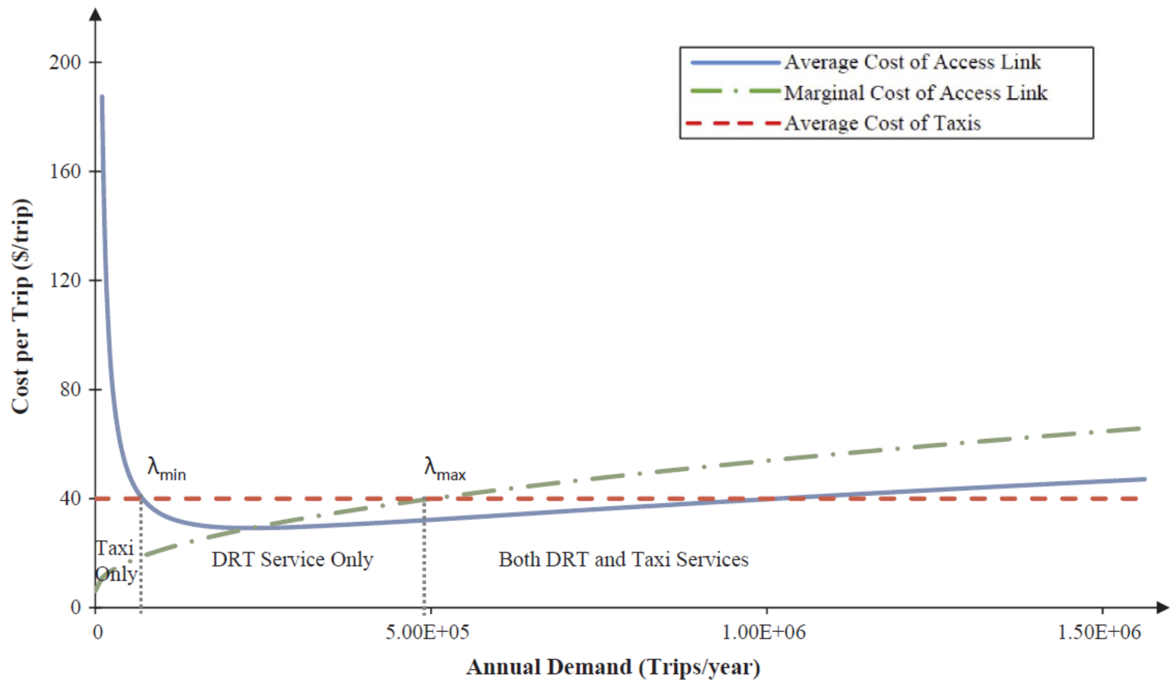

Figure 2 - Threshold for out-sourcing transit rides

Source: Rahimi et al. (2018)

2.4. Conclusion

In order to create a framework for evaluating different options of last-mile service in low-density areas, the factors that influence the decision of choice riders regarding transit use as well as performance measures that transit providers employ to evaluate their system were explored in this chapter.

Aside from personal and cultural differences, the following attributes of transit system have a considerable effect on transit ridership:

- Travel time that takes to reach high-frequency transit service, including waiting time
- Coverage: spatial accessibility of transit
- Transit service span and frequency
- Cost including fare payment
- Safety & security
- Physical comfort
- Access to information

This suggests that if transit providers can expand transit coverage and lower the cost of transit use for choice riders, more people will choose to use transit service. But this shift in transportation mode choice will have a positive effect on transit system performance if it doesn't require using considerably more transit fleet and imply significant cost on transit provider.

From the provider's perspective, cost is a major factor which helps them decide if a service is efficient and/or effective to run. However, a dollar value of running a system is not the most important factor. Instead, cost-efficiency and cost-effectiveness which measured by the number of people using the service and how well it responds to their needs will be considered. Therefore adding to the above factors, how much each last-mile strategy costs per rider for the provider will be considered as well.

The objective of this research is to compare different last-mile option for transit service providers and compare them in a real case study. To accomplish this task, several kinds of literature including academic research, reports and official plans were analyzed to find the strategies that were used before regarding last-mile issue. Following strategies were found and described in this section:

- Promote using personal bicycle and bike-sharing
- Facilitate using personal car and car-pooling
- Informal transit
- Demand Responsive Transit
- Out-sourcing transit rides

Compared to conventional bus service for last-mile service, each strategy has pros and cons that are outlined in Table 7.

Table 7 - Comparing the options for improving last-mile service

	Providing Real-time information	Promote bicycle use	Provide Park & Ride facilities	Informal transit	Mix fleet	Semi-flexible bus service	DAR	Out-sourcing
Travel time from home to frequent transit route	0	+	+	-	-	+	+	+
Waiting time	+	0	+	+	0	+	+	+
Frequency (flexibility of service hours)	0	0	+	+	0	0	+	+
Accessibility (Geographical coverage)	0	+	+	+	0	+	+	+
Cost for rider	0	-	-	+	0	0	0	0
Cost for provider	-	-	-	0	+	+	+	+
comfort	0	0	+	-	0	0	+	+
Safety, Security, and Reliability	0	0	+	-	0	0	+	-
Significant effect on ridership increase	+	-	+	+	-	-	+	+

+ Better - worse 0 no improvement

3. Methodology

3.1. Overview

Based on the important factors that affect last-mile issue from provider's perspective and potential user's perspective adopted from the first two parts of literature review, I want to compare different strategies for tackling the last-mile issue in York Region. As mentioned earlier, an exploration in previous transit efforts documents resulted in 19 studies that compared two or more strategies (e.g. flexible and fix service) based on one or two evaluation criteria (e.g. ridership or cost-revenue rate).

Some of these studies – e.g. Guidelines for Providing Access to Public Transportation Stations (Coffel et al., 2012) and Strategic Station Access Planning (Engel-Yan et al., 2014) – introduced a different strategy to providing access to transit station – such as bike and pedestrian access, Park-n-Ride, and feeder transit. However, these studies were mostly focused on rail transit, regional bus, and BRT stations not the means of access. Talley and Anderson's (1986) analysis was one of the best studies that compared several options from different perspectives. I am going to use a similar approach for evaluating two main strategies (i.e. DAR and out-sourcing rides).

Exploring current practices in my case study (i.e. York Region) shows that YRT already implemented most of the strategies and they claim to be successful in attracting more riders (Committee of the Whole Transportation Services, 2017). Only two options are not considered in their plan: Informal transit and Out-sourcing transit rides. Based on the discussion presented earlier, informal transit is not a viable option for the case of this study as there is no legal and legislative base for implementing it, besides safety and security concerns.

Opportunities for implementing the out-sourcing strategy as an alternative to DAR service are explored.. In this regard, several criteria adopted from literature review, were compared. Some criteria such as safety, security, comfort, ease of implementation and use were discussed later in next chapter using a qualitative analysis approach. These discussions were based on previous studies and mentioned there to supplement the comparison.

Quantitative analysis used for other criteria, such as cost for the provider and spatial and temporal coverage. They were compared based on real numbers adopted from YRT official reports which was the most recent publicly available data from York Region Transit for 2017 and 2016.

3.2. Cost for provider

As described in the literature review, cost and ridership are the major factors for transit providers. They want to maximize the number of people using transit while minimizing the cost for providing that service. My goal was to shift transit routes that have a low performance with current on-demand or fix-schedules service and examine the opportunity to improve their service by out-sourcing the riders.

Therefore, in order to select the least efficient routes in the region, two types of available data are used: an average net cost per passenger and ridership number of each route.

Cost per passenger for each route were collected from official reports. These numbers were reported separately for different times during the week (i.e. weekday rush hour, weekday non-rush hour, Saturdays and Sundays). This cost consists of the contractor rate plus fuel price. Then those routes which cost of operation is more than three times of the average transit fare are selected for further study.

Then the average number of boarding for selected routes are extracted from official reports. In order to have a better understanding of each route efficiency, the number of passengers per trip and the ratio of the average numbers of passenger per trip are calculated. This ratio is used to evaluate service efficiency.

Those routes that have a high number of passenger per trip were subtracted from the list as they are not a good candidate for on-demand services and could be better served with high capacity vehicles.

3.3. Spatial access to transit

Besides the cost of providing service for each passenger, I paid attention to the opportunity to increase transit ridership. Based on my literature review, increasing the areas that have access to transit within walking distance and the time span that transit service is provided to the public will have a positive effect on transit ridership. Also by adding flexibility to the service, we can expect that more people select public transit for their mobility needs. By that transit effectiveness will improve.

Therefore, I decided to measure the current spatial coverage of transit service by calculating the area that is located within walking distance of a bus stop, plus all the area that have access to on-demand curb-to-stop service. 400m is an acceptable walking distance according to the official transit plan and many academic pieces of literature (e.g. Vuchic (2005)).

Transit stop locations are adopted from GTFS data of York region and I used GIS software to calculate create a spatial coverage map and calculate the area within 400m buffer of a bus stop. The coverage is calculated for the whole York Region, considering current fix and DAR service. It is assumed that by offering on-demand service through individual contractors (i.e. out-sourcing transit rides) in the whole low-demand area, people living there will have full curb-to-stop coverage and can access to high-frequency transit lines from any place in that region.

3.4. Temporal access to transit

For temporal coverage, I looked at each non-efficient route schedule separately and assigned a 15-minute time frame as waiting time for each bus service, and accumulate them with the whole time that on-demand service (DAR) is available in that area. Transit service schedule used for this calculation is adopted from YRT official website in 2018. The 15-minutes waiting time was also used in the literature mentioned in table 3.

Consequently, I reached a total number of hours that someone can comfortably have access to transit for the area that each route covers. As the service schedule is different for different times of the week, I have measured the temporal access based on weekly hours. This method for temporal coverage measurement is more realistic and can reflect the frequency of service which is an important factor affecting the potential rider's decision toward transit use.

It is assumed that by out-sourcing service to companies like Uber and Lyft, people can send a request at any time, and their access to main transit line won't be limited, however, as there is no obligation for the individual service providers and there won’t be any dedicated driver, people might face difficulty when not enough drivers are willing to work

In the next chapter, I will delve into a case study to compare these three factors (i.e. spatial coverage, temporal coverage, and cost for providers) and find out if out-sourcing can improve transit service in York region.

4. Case Study

4.1. Overview

Transit network design must take into account both the needs of the customer and the transit operator, as well as the practical ability to provide the service. From the customer's perspective, the transit network should provide a convenient and reliable service when and where they need to go, with good customer communication and service. From a system-wide transit operations perspective, the transit network must be manageable, operable, and sustainable – all within the constraints of a fixed operating budget.

The systematic literature review examined different options for last-mile service, particularly focused on low-density areas. Each option can benefit society in several ways. These options may be used in different settings based on the characteristics of the settings (e.g. funding, environmental requirement)

This section summarizes policy objectives and issues with the currently existing public transit services operating through York region. Thus, the settings of the selected study areas for this research are explained along with current practices and plans in the region. The options for providing last-mile transit service in low-density areas within York Region will be compared based on the criteria selected in chapter 3, which are also aligned with transit authorities' visions and goals.

4.2. Introduction to York region case study

4.2.1. Transit in York region

The Regional Municipality of York, also called York Region, is located in Southern Ontario, Canada, and consist of nine municipalities (Figure 3): Town of Georgina, Town of East Gwillimbury, Town of Whitchurch-Stouffville, Township of King, Town of Newmarket, Town of Aurora, Town of Richmond Hill, City of Markham, and City of Vaughan. The first four municipalities have more rural character than the rest. Based on the 2016 census, it has over 1.1 million residents and 0.6 million jobs over a 1,776 Km^2 area (Statistics Canada, 2018).

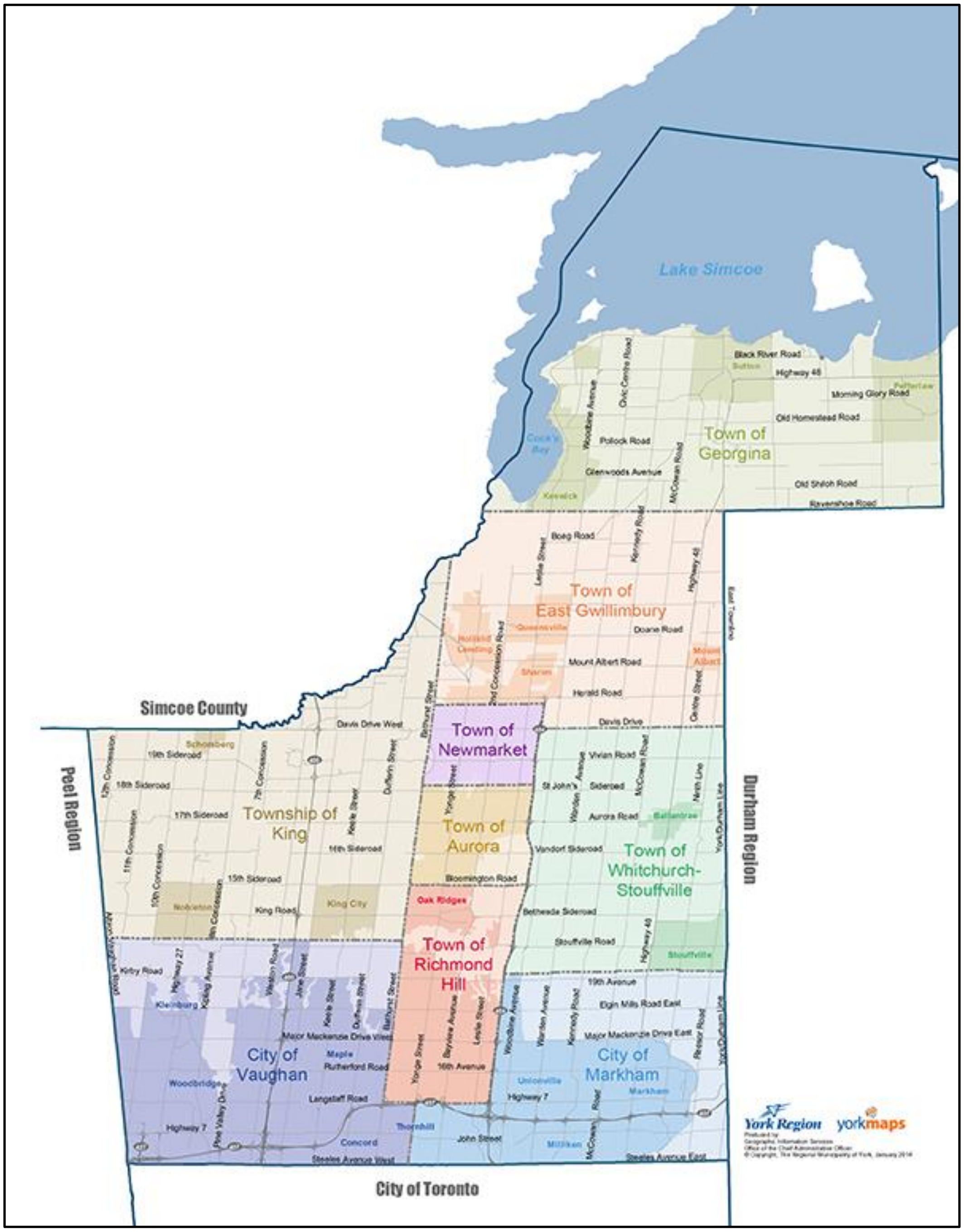

Figure 3 - York region location

Source: The Regional Municipality of York (2014)

York Region is one of the fastest growing regions in Canada with 19.6% population growth in the last decade (2006 to 2016) compared to 11.2% national growth (Statistics Canada, 2018). The population density and related transit demand are not homogenous in this region because of the noticeable differences in where people decide to live. Close to the city of Toronto and along Yonge Street are the most popular areas in the region. There is a nodal urban growth pattern in the region.

As Figure 4 shows, the southern and center part of the region has higher density areas compared to the outer more rural part of the region. Accordingly, the transit system offers more frequent service in the southern part of York region and along Yonge Street as the main transit corridor of the region. This part is the home of the major urban centers (city of Vaughan, Richmond Hill and Markham) and has the most frequent public transit service.

However, a simple comparison of population density and the ratio of people using public transit as the main mode of their commute (Table 8) shows that these two are not related. When the transit network map (Figure 5) is taken into consideration, we can see that more people use public transit because of its availability, as in the city of Markham, Vaughan and Richmond Hill where we can see the highest level of public transit use, although Newmarket has the highest population density in the region. Even, Aurora has a higher share of public transit compared to Newmarket, although the population density of Newmarket is almost twice as Aurora. Obviously, all four towns (Whitchurch-Stouffville, East Gwillimbury, Georgina, and King) that have the lowest public transit usage, has very small coverage of public transit as well.

Table 8 - Population in 2016 and density of York Region

	Population	Population Density (per Km^2)	Main mode of commuting (Public transit/private vehicle)
Town of Newmarket	84224	2190.5	0.107
Town of Aurora	55445	1112.3	0.131
Town of Richmond Hill	195022	1928.8	0.188
Town of Whitchurch-Stouffville	45837	222.3	0.074
City of Markham	328966	1549.2	0.202
Town of East Gwillimbury	23991	97,9	0.051
City of Vaughan	306233	1119.4	0.153
Town of Georgina	45418	157.8	0.032
Township of King	24512	73.6	0.057
York region	1109909	629.9	0.152

Source: 2016 Census Report, Statistics Canada (2018)

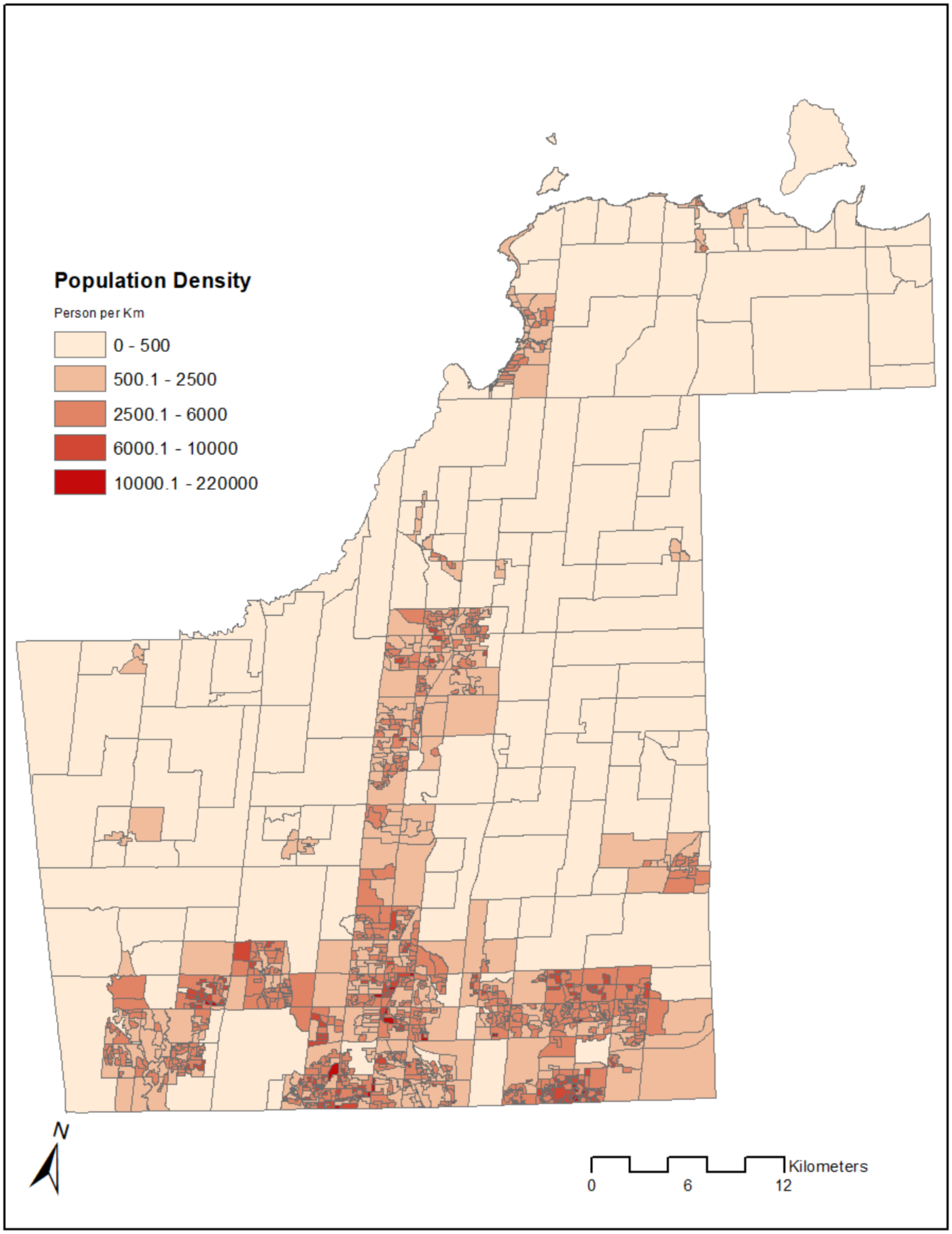

Figure 4 - York region population density based on census data 2016

Source: York region open data, York Region Transit (2018)

Figure 5 shows the official transit map of the York region including current and future transit services. York region is served by three transit operators with each having different regulations and fare policy:

- York Region Transit (YRT)
- Go Transit
- Toronto Transit Commission (TTC)

There are five TTC bus routes operating directly between York Region and the City of Toronto, offering a convenient way to connect York region transit riders to the Toronto transit network without changing buses. This service connects York region transit rider to subway stations. Riders pay an extra $3 to use this service when they cross the Toronto municipal border.

Go transit, controlled by Metrolinx, offers regional bus and train services that connect York region to Toronto, Durham Region, and Peel Region. Go transit service fares are based on distance. Go transit riders can pay an extra $1 to use YRT service connected to GO transit or use Park-n-Ride facilities which offer free parking for Go train users in all York region's Go train stations. Compared to driving a car, Go transit provides a convenient, low-cost commute to other regions, particularly downtown Toronto.

YRT offers local and rapid bus service _Viva Bus, as well as on-demand services Dial-A-Ride and Mobility Plus. YRT has almost 140 routes that keep residents connected within York Region, as well as connecting services to the surrounding areas. Currently, The YRT fleet is consist of:

- 123 Viva vehicles operate on 6 routes
- 406 conventional YRT buses on 137 bus routes
- 97 Mobility Plus vehicles

It should be noted that the areas with white and orange colors which have low-density of residents are the main focus of this research. However, further examination will show that most part of urban areas on the north of Richmond Hill up to Simco Lake can benefit from the same strategy proposed for rural areas.

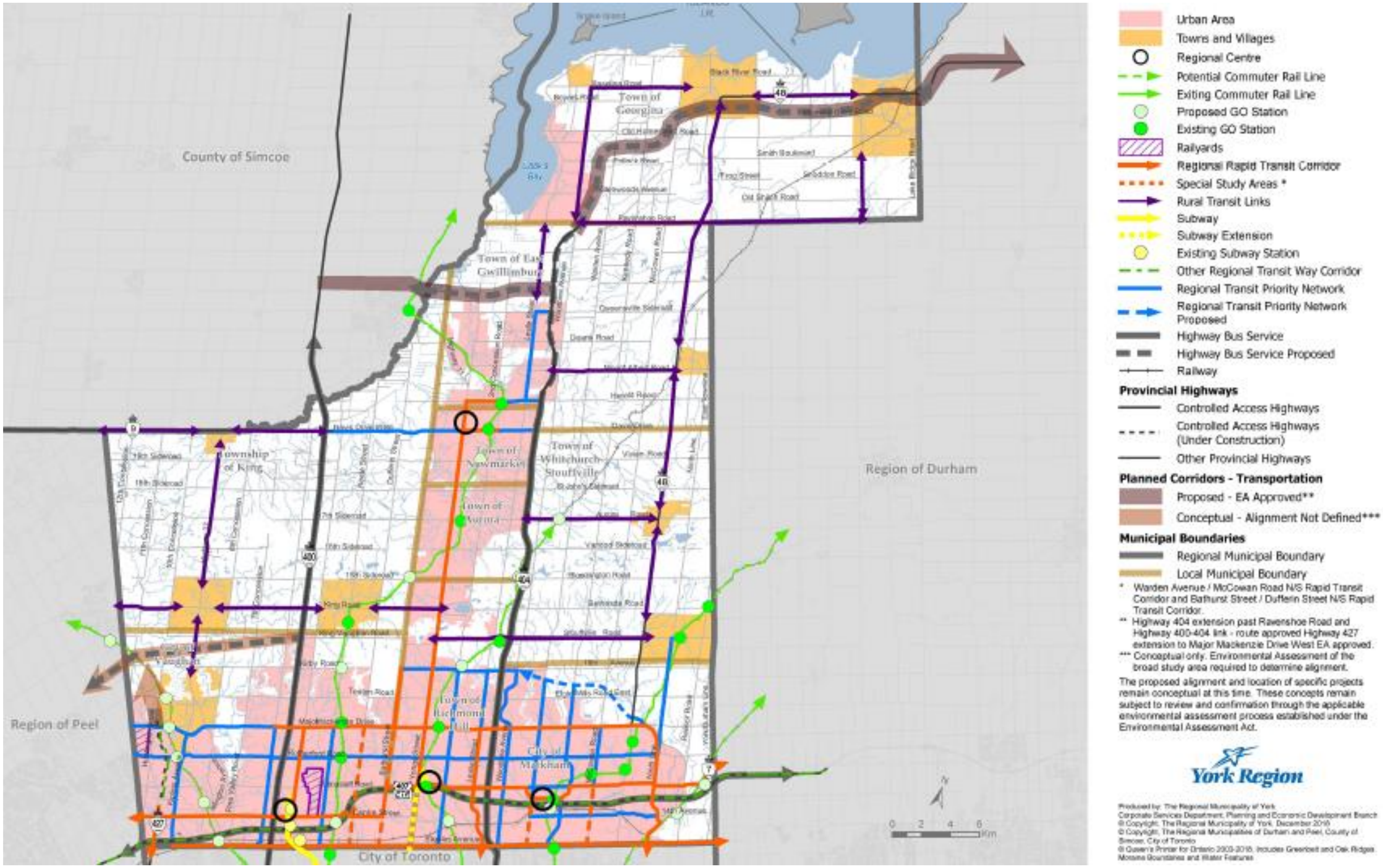

Figure 5 - York region transit map
Source: The Regional Municipality of York (2019)

Figure 6 shows the current YRT routes in the region. York region's General Transit Feed Specification (GTFA) database (York Region Transit, 2018) was the source of information for creating this map. This map shows that in most part of the region, there is only one conventional (i.e. fixed schedule) bus service that is not accessible for people living in low density areas.

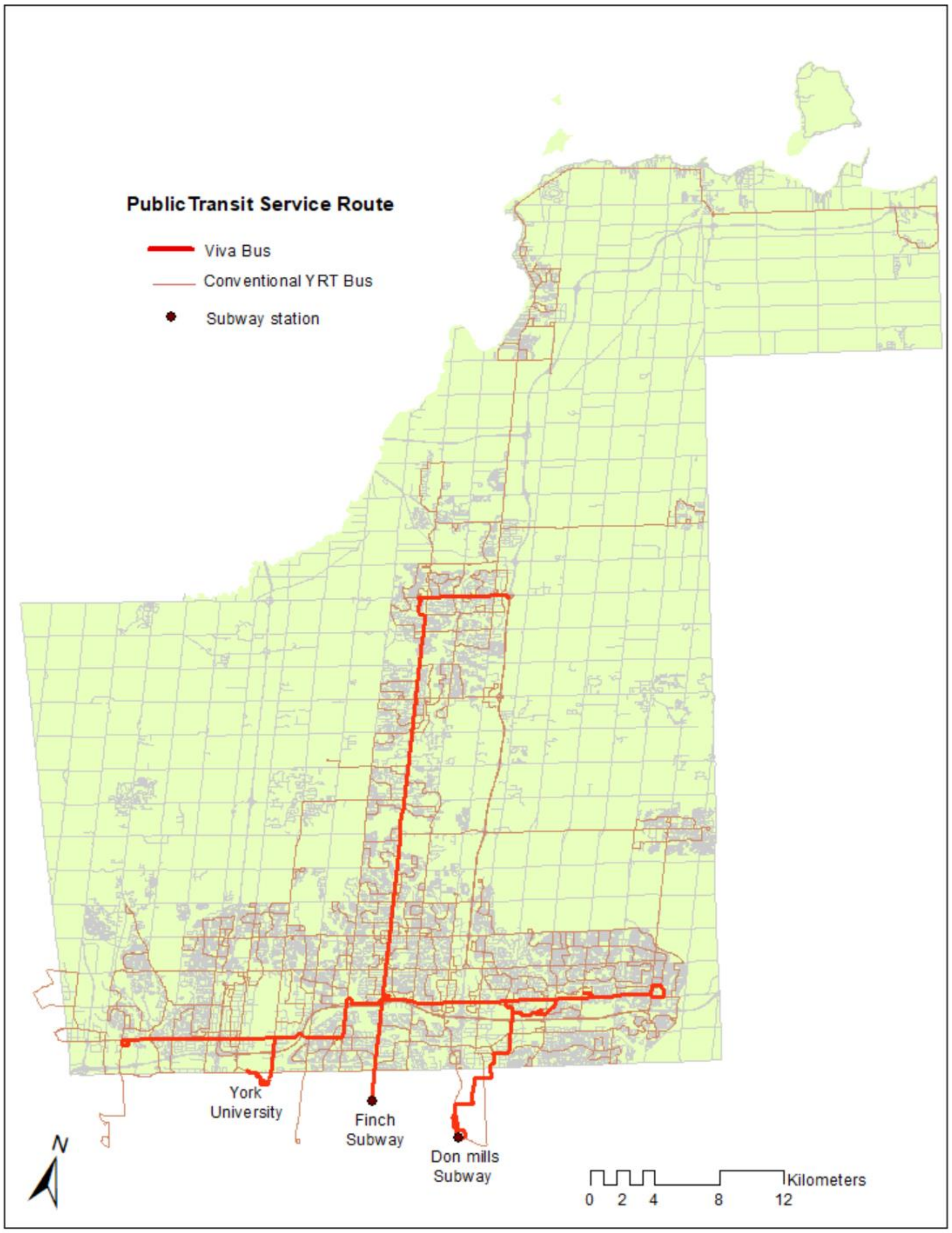

Figure 6 - York region YRT and TTC transit map

Source: York region GTFS data, York Region Transit (2018)

In 2017, YRT had 22.8 million passenger trips, 1.4 million hours of service, 31 million kilometers of service. On average, 76690 passengers were moved by YRT each week. The highest ridership was on Viva Blue – connecting Finch subway station to Newmarket terminal through Yonge Street- with 17808 passengers per week (York Region Committee of the Whole Transportation Service, 2017 pp.3).

Viva buses offer high-frequency express service along main transit corridors in the region. They have fewer stops and in some areas use dedicated roadways. They are supposed to run as a BRT system in most part, but currently, just two east-west corridors (Hyw 7 & Davis drive) have dedicated lanes for Viva. The main south-north corridor that Viva serves is along Yonge Street and the dedicated lines are under construction and will be completed by 2020 (Metrolinx, 2019).

Mobility Plus provides transit service only for individuals who are not able to use regular bus service because of a disability. It is a door-to-door, shared ride service for registered residents who meet specific eligibility criteria. Mobility Plus has three options for registered clients to book, cancel and confirm trips: online, Interactive Voice Response (IVR), with a trip reservationist. Mobility plus had 12000 registered member and completed 408000 trips in 2017 (York Region Committee of the Whole Transportation Service, 2017 pp.3).

Conventional buses are serving the York region at a different level. Their frequency of service and service time span are ranging from every 10 minutes in rush hours to one per hour in for regular routes mostly from 6 a.m. to 10 p.m. during the week and very limited services on weekends. Aside from regular and local bus services, there are shuttles and community bus services which serve high schools and shopping centers. These buses only work a few times a day or just some days during the week.

From a financial standpoint, YRT receives capital subsidies from the federal and provincial government. Transit fares cover almost 40% of YRT operation costs (York Region Committee of the Whole Transportation Service, 2017 pp.9). Average YRT fare is $3. YRT tickets offer two-hour transfers, letting people travel on any YRT vehicle for up to two hours, in any direction, with a single fare.

YRT contracts out its service to four private bus contractors, who employ the bus operators and maintain the YRT fleet. Performance-based contracts with each contractor ensure the system is always meeting YRT's high standards.

Flexibility is added to general YRT services in two forms: Flexible stop, and Dial-A-Ride (DAR) services. Flexible stop means when people ride use public transit after 9 p.m., they can get off between stops, closer to their destination just by informing the bus driver at least one stop ahead.

DAR is a demand-responsive service that connects travelers to their requested stops and operates on a first-come, first-serve basis. It is offered in low-density residential areas as a feeder service to main bus routes and as a substitute for evening and weekend bus service. DAR offers two levels of service: In low-demand urban areas, DAR allows direct travel between YRT stops within a predetermined geographic area. Which means it does not follow the exact route of bus service, but picks up people at one transit stop and drops them at another one (Stop-to-Stop). However, in the rural area, DAR works as a first/last mile transit service and picks up people from any address in that area and takes them to a requested transit stop and vice versa (Curb-to-Stop). This service is available to everyone by a reservation. To make a trip during the service hours, a call should be made to DAR at least 60 minutes in advance. Customer service representatives will assist with trip planning. People may have to wait up to 60 minutes to allow the DAR vehicle to complete other trips. DAR service operates on a first-come, first-serve basis. Figure 7 shows the current service type that DAR offers.

Another service that YRT offers to facilitate transit use is free parking in areas close to major transit stops so people can use their personal vehicle for the first/last mile of their trip and thus increasing the potential to use public transit on high-frequency routes. For those who can use their personal bicycle as the first/last mile of their trip, there are 182 bicycle racks located at key stops across York Region and all YRT buses are equipped to hold two bicycles.

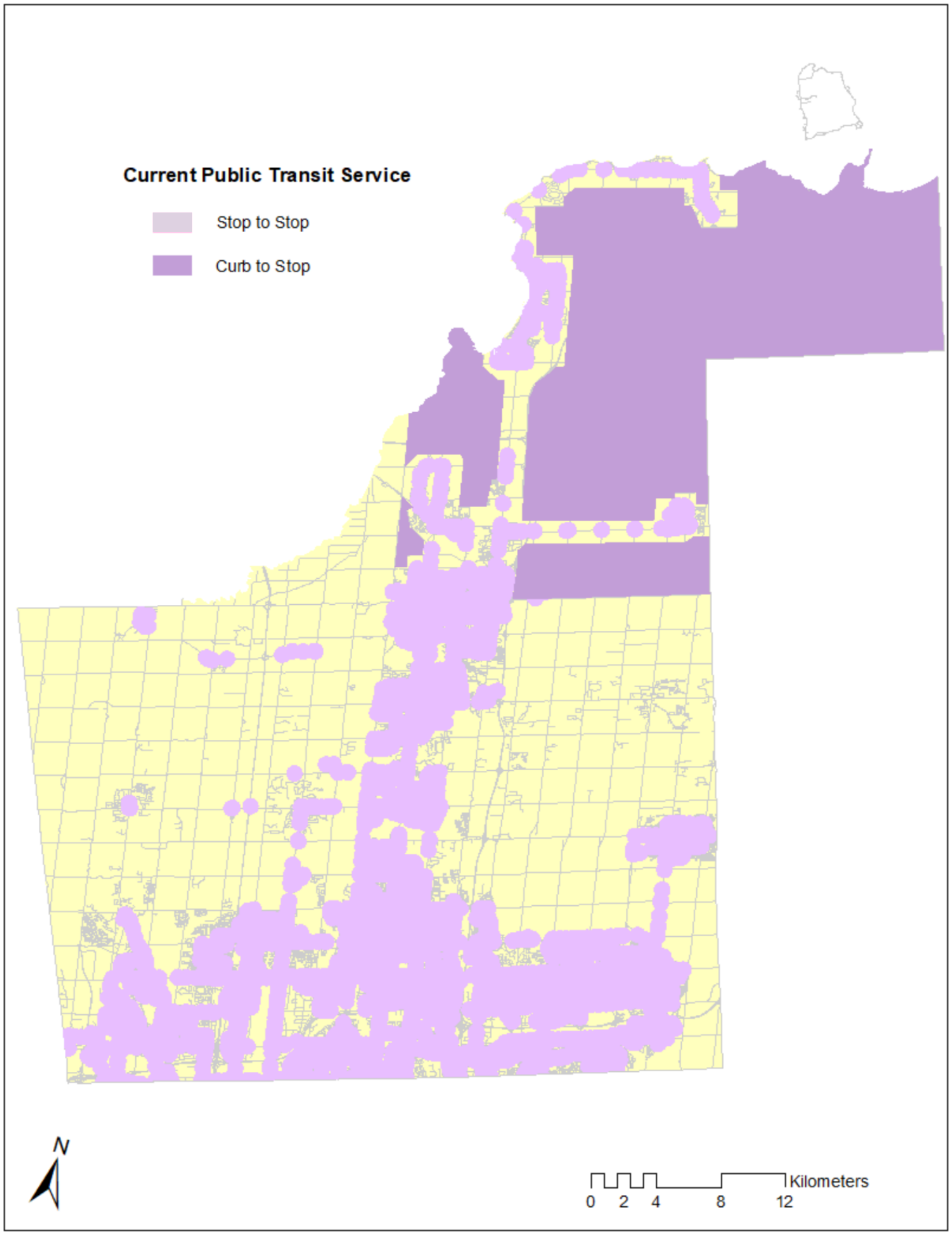

Figure 7 - YRT service type

Source: York region GTFS data, York Region Transit (2018)

Also, by providing real-time information through implementing Variable Messaging Systems (VMS) boards at every Viva station and a real-time App (official YRT app) for mobile devices, YRT help riders to more accurately plan their trip so the travel time and waiting time become shorter and eventually increase user satisfaction with public transit service.

York region transit has been studied for years and several plans have already prepared to overcome transit challenges, directing efforts toward investment and evaluation of YRT services. Their objectives and standards are discussed in the next chapter in order to have an overall idea about the direction YRT is expected to follow.

4.2.2. Current transit performance standard based on official plans

There are several plans directing York region transit services, including:

- The Regional Municipality of York Transportation Master Plan 2016 (The Regional Municipality of York, 2016)
- Moving to 2020, YRT/VIVA 2016-2020 Strategic Plan (York Region Transit, 2015) and its update (York Region Transit, 2017)
- 2018 Transit Initiatives (York Region Committee of the Whole Transportation Service, 2017)
- On-Demand Transit Strategy (York Region Transit, 2016)
- On The Move, toward sustainable transportation, key issues, and challenges for York region (Consult Limited, 2000)

Although the York Region Transportation Master Plan has the widest scope compared to others, the last mile issue was specifically mentioned in this plan. The following major initiatives were offered in this regard:

- Provide safe and convenient walking/cycling opportunities to mobility hubs
- Manage parking supply and demand with innovation, pricing, and technology
- Support transit-oriented development
- Embrace emerging technologies and the sharing economy to improve convenience and mobility
- Educate and encourage the public on their mobility options through strategies, programs, and incentives that support non-auto travel

YRT's 2016-2020 Strategic Plan was approved by York Region Council in September 2015. It was developed to guide staff in the planning and delivery of transit service to the residents of York region. Consequently, a set of performance indicators were established as target indicators (Table 9). Performance is measured for the whole YRT/Viva system and for each individual route. System performance is measured with five key indicators:

- Amount of service (service hours per capita)
- Service effectiveness (ridership per capita)
- System ridership performance (passengers per operating hour)
- Economic performance (revenue to cost ratio)
- Mobility Plus performance (Mobility Plus passengers per operating hour)

Route performance is measured with five key indicators, of which three apply to conventional services and two apply to Mobility Plus:

- Ridership target (passengers boarding per operating hour)
- Cost-effectiveness (net cost per passenger)
- On-time performance target (on-time performance)
- Mobility Plus cost-effectiveness (net cost per passenger)
- Mobility Plus on-time performance target (on-time performance).

According to Moving to 2020, the YRT service coverage target for an urban area is 90% of residents within maximum walking distance of 500m to a bus stop. For a rural area, the target is 90% of residents within maximum walking distance of 1000m to a bus stop where transit provided. In general, the span of service for the overall system is 6 a.m. to 10 p.m., although individual routes may have different service span based on the demand (York Region Transit, 2015). The minimum threshold for each service was defined that would be used in the evolution of the system (Table 10).

Table 9 - YRT Performance indicators target

Amount of service	1.2 service hours per capita by 2020, and 1.5 service hours per capita by 2031
Service effectiveness	30 Passengers per capita
System ridership performance	35 passengers per operating hour
Economic performance	Overall revenue to cost ratio of %45
Mobility plus performance	2.5 passengers per operating hour

Source: York Region Transit (2015) pp.39

Table 10 - Minimum ridership target

Viva and base service	35 passengers boarding per hour
Local service	25 passengers boarding per hour
Express service	35 passengers boarding per hour
Shuttle and community bus service	15 passengers boarding per hour
Dial-a-Ride service	10 passengers boarding per hour

Source: York Region Transit (2015) pp.40

"York Region Transit Initiatives 2018", was created based on the "Moving to 2020 Plan". In this document, several performance indicators were used to evaluate the YRT system performance. The main indicators were as follows:

- Average route ridership,
- Average route ridership per hour,
- Net cost per passenger – net cost to operate a route divided by the number of travelers
- Revenue-to-cost ratio – revenue collected through transit fares compared to the cost to operate service

Unfortunately, the performance indicators used in this report were not the same for all routes, probably due to lack of information. Each year, YRT publishes an annual report that shows how well the YRT system works mostly based on these indicators.

The York Region "On-demand Transit Strategy" outlined a framework for delivering demand responsive transit service to low-density areas. The main objectives of this plan are:

- Improve service efficiency
- Increase ridership
- Expand service area coverage
- Promote the use of public transit
- Connect customers to main transit corridors
- Continue to develop innovative transit services (York Region Transit, 2016)

In this report, conventional bus, Mobility plus and Dial-A-Ride service were compared based on the following parameters:

- Meets first/last mile
- Ease of implementation (easy to communicate, implement fleet, and implement software)
- Customer experience
- Staff resources
- Technology availability
- Contractor
- Relative cost
- Average passenger trip length
- Average cost per passenger
- Cost per kilometer
- Safety

After comparing three scenarios for a Dial-A-Ride system, including the current system, zone-based model, and route-based model, the zone-based service delivery model out-performed all other models from a customer, cost and operational perspective. Figure 8 shows the proposed zones of On-demand service. The timeline for implementation of this plan started in 2017 and goes beyond 2020. Based on this plan, rural residents will receive curb-to-stop service, but suburban and urban residents will receive stop-to-stop service.

Later in this chapter we see that zone number 1, 2, 3, 5, 6, 18, and 19 has the lowest efficiency, imply the highest cost for provider, and have the lowest ridership number.

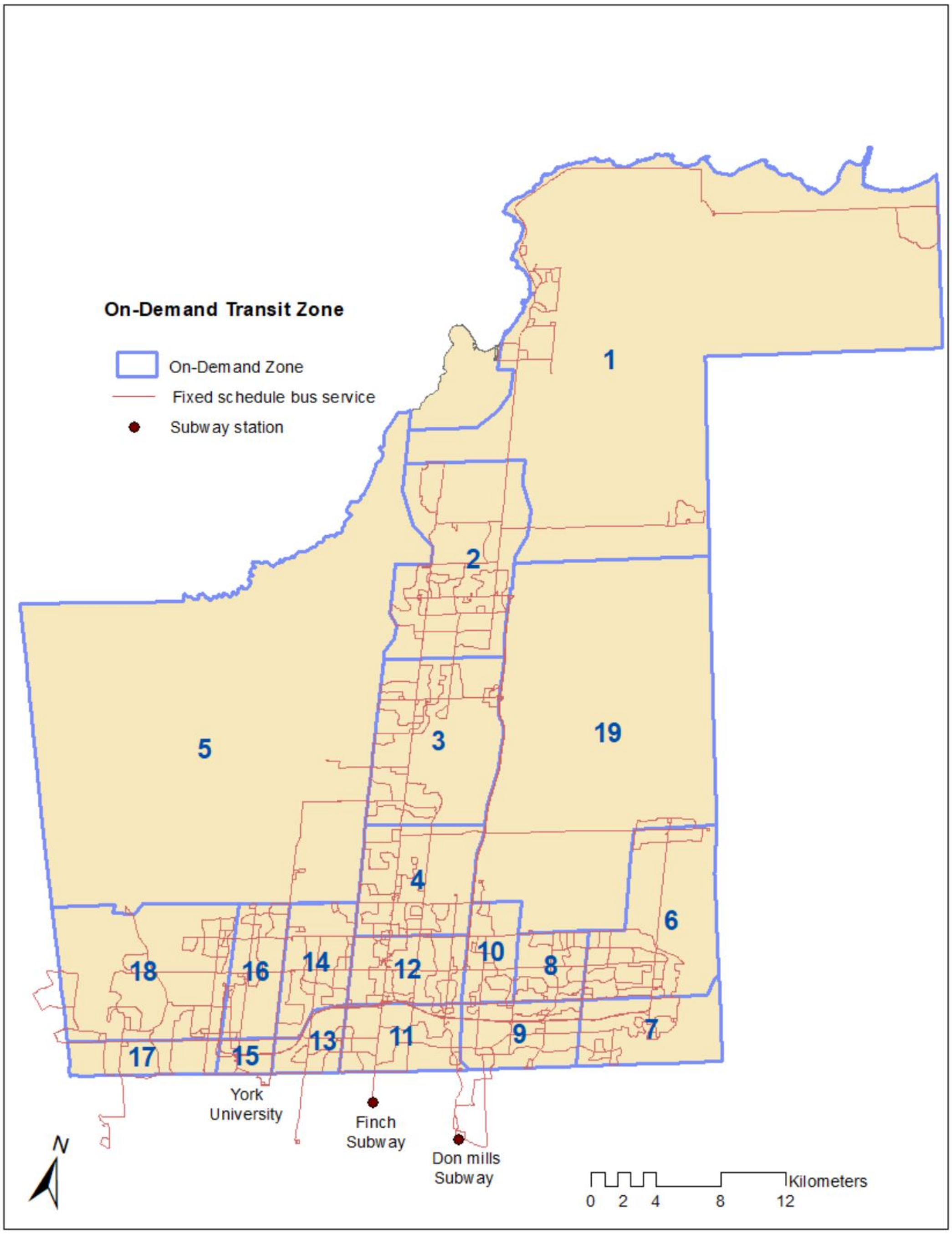

Figure 8 - YRT on-demand transit zone map

Source: On Demand Transit Strategy, York Region Transit (2016)

4.2.3. York Region Transit problem statement

Providing access to public transit is one of the main challenges of transit providers in York region. A large portion of the York region is made up of geographically-segregated and low-density communities that require frequent travel to urban centers to fulfill most of their basic daily needs. Low density and spatial heterogeneity of these areas impose a considerable challenge to both transit riders and service providers. Low-demand forces transit agencies to provide sparser and less geographically accessible service so as to stay economical, yet it has been argued that this further deteriorates passenger experiences and deters patronage (Nourbakhsh, 2014).

According to York Region Transit Performance Report (2018), YRT was behind its target in all indicators, except on-time performance (Table 11). For example, the overall revenue-to-cost ratio for YRT was 40% in 2017. YRT's revenue ridership - the number of paying travelers using the service - increased by 1.2 percent from approximately 22.8 million in 2016 to 23.1 million in 2017. Despite improvements, YRT service excluding Viva was considerably lower than the target and have not changed since 2006 (Figure 10 Appendix).

Table 11 - Comparison of the current situation to the targeted measures

Indicator	Unit	Target	Current
Amount of service	service hours per capita	1.2	1.16
Service effectiveness	Passengers per capita	30	19
System ridership performance	Passengers per operating hour	35	16.3
Economic performance	Overall revenue to cost ratio	45%	40%

Source: 2018 Transit Initiatives (York Region Transit, 2017) & YRT Transit Performance 2017 (York Region Committee of the Whole Transportation Services, 2018)

Viva buses have generally high ridership and consequently, have lower cost ratio. Viva Blue is the most efficient bus service in the region, while Viva Green is the least efficient. Viva Purple and Orange are also behind their performance target. TTC running routes are generally moderate in ridership and cost. They cover the main roads, north-south connecting subway stations to York region, and mostly run in the high-density neighborhoods.

From an economic perspective, in September 2017, even in weekday rush hour, only 4 routes had positive revenue. 41 routes cost per passenger were equal or smaller than regular transit fee ($4), while for 24 route cost more than twice transit fare up to $45 per passenger. The situation was even worse for non-rush hour and weekends. Graphs in figures number 11 to 14 in the appendix show the net cost each passenger imposed on the service. The similar situation was reported for 2016 as well (York Region Committee of the Whole Transportation Services, 2017).

Although the economic parameters of YRT performance didn't improve in recent years, accessibility and the quality of service has increased since 2015. On-time performance as a measure of service quality improved in all three sections - conventional local bus, Viva and Mobility Plus services-, all of them working above the targeted standard.

4.3. York Region and last-mile service

Considering the development pattern in York region and transit inefficiency, two main service objectives could arise:

- Solving the problem of low performance and inefficient transit services in areas that have access to transit but demand is low and can't support frequent service. Some of these areas are served by buses that are often empty. Others are served by on-demand transit (DAR), yet still, impose a high cost per passenger on YRT.
- Providing access to transit for areas that are located in the York region but currently don't have any access to YRT network. YRT can't provide service to these areas due to efficiency standards. The concept of equity in access to transit will arise in these areas.

For both situations, demand-responsive service is a possible solution, because of the low and scattered demand. The question is whether YRT should have dedicated drivers, fleets, and staffs for serving these areas, or they can outsource the rides to ridesharing companies like Uber, similar to Innisfil. However, in the case of Innisfil, authorities were sure that outsourcing is more cost-effective because there was no transit infrastructure in place and the initial cost of buying fleet and providing service was high. But in case of

York region, there are some infrastructure in place and currently serving the area, yet one goal is to cancel some of the highly costly bus routes without losing ridership, so the cost of transit goes down (based on current metrics).

In the following section, the inefficient YRT services (Bus or DAR) are recognized, then their current situation and their future based on official plans for YRT are examined against another option for providing service – outsourcing the rides to private companies.

Subsequent to the literature review in chapter two, the following criteria were selected for comparing last mile solutions in the York Region:

- Spatial access to transit
- Cost for provider
- Spatial access to transit
- Ease of implementation and use
- comfort
- Safety

Two alternative systems for providing on-demand transit services are examined: Dial-A-Ride and Outsourcing transit rides to a ridesharing company. They are analyzed based on publicly available data from York Region Transit.

4.3.1. Spatial access to transit

From a mobility perspective, a combination of the transit map of York region and their schedules reveals that only the southern part of the region is fully accessible by public transit for at least sometime during the day. In order to evaluate the YRT geographic coverage, I used GTFS data to locate transit stops in a GIS basemap, and then construct a buffer zone of 400m around each stop to represent the walking accessible distance of transit stops (Table 12).

Moreover, the DAR coverage area of North zone, which currently serves residents of the north part of York region was added to Table 12. People from any location in this area (431 Km^2) have access to this service. Figure 7 also presents the spatial accessibility of York region transit. The yellow area in the map is considered as having no access to DAR service. Initiating this service almost doubled the coverage area, however, due to the high cost of implementation (close to $50 per passenger), its performance needs reconsideration.

Table 12 - YRT spatial coverage

	Area (Km^2)	Within 400m of bus stop (Km^2)
Town of Newmarket	38.2	29.9
Town of Aurora	49.4	25.2
Town of Richmond Hill	101.5	70.2
Town of Whitchurch-Stouffville	211.1	13.8
City of Markham	1212.7	109.5
Town of East Gwillimbury	247.6	27.8
City of Vaughan	274.3	123.1
Town of Georgina	289.5	28.1
Township of King	333.6	7.6
York region	1761	435.2

Source: York region GTFS data, York Region Transit (2018)

Currently, most neighborhoods have stop-to-stop DAR service, except DAR North which offers Curb-to-Stop service to those living outside of walking distance of transit stops (green area). If they live in walking distance (orange area), they can use conventional buses or DAR service when it is available (Figure 9). Service type in Table 15 is based on the On Demand Strategy of YRT. In the future, Whitchurch-Stouffville and King area will also have Curb-to-Stop, but for now, these areas are only served at the Stop-to-Stop level.

On the other hand, unlike current DAR service (Table 13), out-sourcing the rides will provide Curb-to-Curb or Curb-to-Stop service. The service area could be expanded under this option to cover the whole region, which is considerably more than the current YRT coverage. Moreover, the timing of the ridesharing service is not limited and potentially provides more accessibility to transit service throughout the day, 7 days a week.

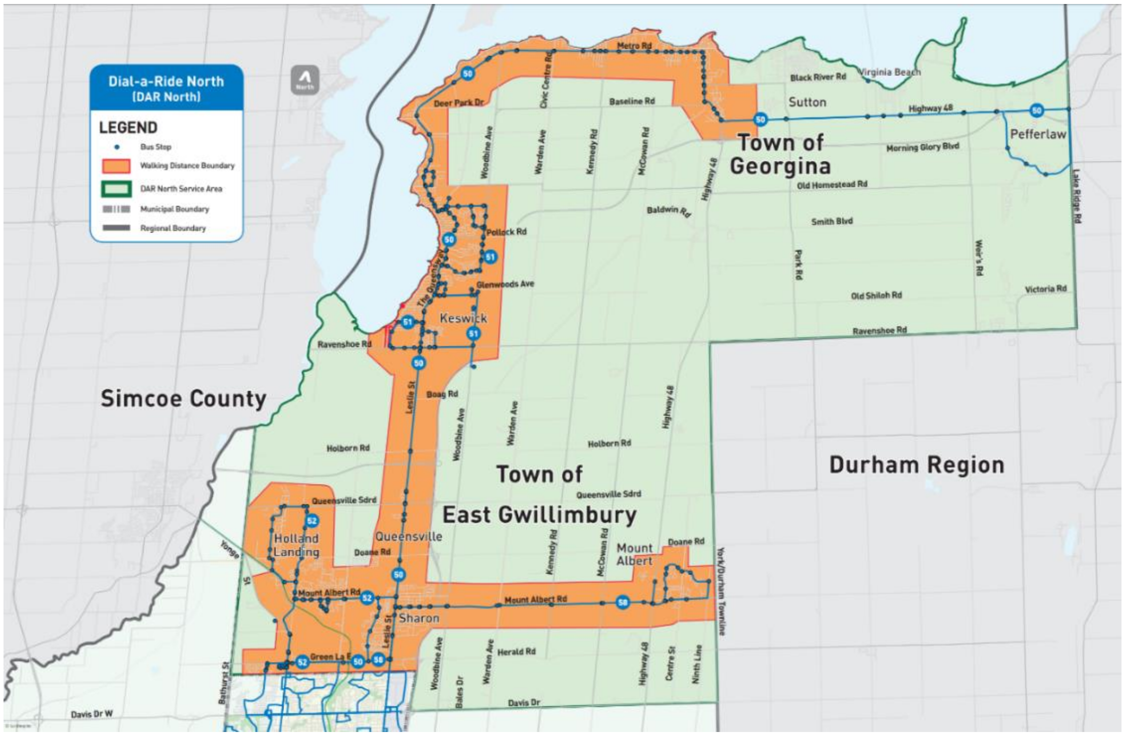

Figure 9 - DAR North service area

Source: York Region Transit (2019)

Table 13 - DAR spatial coverage

Route number	Route name	zone	Service type
10	Woodbridge	18	Stop-to-Stop
15	Stouffville	19	Curb-to-Stop
40	Unionville local	10&8	Stop-to-Stop
41	Markham local	6	Stop-to-Stop
52	Holland landing	2	Stop-to-Stop
58	Mount Albert	1	Curb-to-Stop
61	King local	5	Stop-to-Stop
	Sutton-perfferlaw	1	Curb-to-Stop
84	Oak Ridge	2	Stop-to-Stop
31	Aurora North	2	Stop-to-Stop
44	Bristol	2	Stop-to-Stop
56	Gorham-Eagle	2	Stop-to-Stop
520/521	Newmarket community bus	2	Stop-to-Stop
32	Aurora South	2	Stop-to-Stop
50/50A	Queensway	1	Curb-to-Stop
51	Keswick local	1	Curb-to-Stop
	Mapleglen Community	16&18	Stop-to-Stop
	Blue Willow Community	16&18	Stop-to-Stop
	DAR North	1	Curb-to-Stop

Source: On Demand Transit Strategy, York Region Transit (2016)

4.3.2. Cost for provider

In this section, the operation cost of providing transit service for YRT- which includes contractor rates plus fuel cost- are compared to the price of ridesharing service on the same road.

In order to have a more detailed view on transit route efficiency, an average net cost per passenger for a different time of the week, officially reported for September 2017 were evaluated. Table 16 in the appendix shows the net cost per passenger and number of passengers, for the routes that cost more than twice the average fare of $3.08. This cost consists of the contractor rate plus fuel price.

Cost per passenger for each route were collected from official reports. These numbers were reported separately for weekday rush hour, weekday non-rush hour, Saturdays and Sundays. Those routes for which cost of operations is more than three times the average transit fare were selected for further study.

Next, the average number of boarding for selected routes were extracted from the Transit System Performance Report 2018. Then the ratio of the average number of passenger per trip is calculated as it is the basic metric that reflects the cost of providing transit service. This number is very low, considering that all trips performed by full-size bus, and most of the time buses are moving around almost empty. Even for best performing routes in the region, for instance, route 88, which has 33 passengers per trip on a weekend, and 37 passengers per trip during the weekdays. Extracted from these data, Table 16 also includes weekly ridership lower than 1000 per operating day.

As expected, routes with a low passenger per trip rate have a higher cost. Those routes that have a high number of passenger per trip were subtracted from the list as they are not a good candidate for On-demand services and could be served with high capacity vehicles. Then hours of service and number of service during the week were calculated based on schedules available on the transit provider website.

Ridesharing cost is collected from a website that compares different ridesharing apps. These prices were calculated for the longest route that someone in the region can take to the closest YRT main transit line. I used RideGuru website to get the price for the top three ridesharing companies (i.e. instaRyde, Lyft, and Uber) that served the region.

The results are presented in Table 14. By contracting out the rides in these areas, YRT will compensate the drivers the difference between service fee and transit fare (average $3) which is much lower than the cost YRT would have to bear for providing the service through current contractors.

Table 14 - Cost comparison for different last-mile options

Route number	Route name	DAR cost			Ride-sharing cost		
		Weekday rush hour	Saturday	Sunday	InstaRyde	Lyft	Uberpool
10	Woodbridge	41.3		101	12	11.7	13
15	Stouffville	64.7		102	20.7	17.5	21.7
28	Huntington	18			16	14.3	17
31	Aurora north	35.6	27	28	7.6	8.3	8.6
32	Aurora south	35.6	27	28	15.5	14	16.5
40	Unionville local	41.3	49	166	12.2	11.8	13.2
41	Markham local	41.3	42	133	10.6	10.6	11.7
44	Bristol	81.5	82	76	6	7.3	7
50/50A	Queensway	35.3	47	114	30	-	-
51	Keswick local	35.3	47		12.5	-	-
52	Holland landing	41.3	26	28	15	13.6	-
56	Gorham-Eagle	119.1	91	45	6.5	7.5	7.7
58	Mount Albert	41.3	32	24	19	-	-
61	King local	100.6 (26 non-rush hour)			20-27	-	-
84	Oak Ridge	38.8	25		12.8	12	13.8
	Sutton-perfferlaw	35.3	47		17.5	-	-

Source: RideGuru (2018); York Region Committee of the Whole Transportation Services (2018)

Table 14 also reveals:

- Although some TTC routes were in the list of high cost per passenger routes, considering ridership per service hour, TTC routes are not a good candidate for outsourcing the rides as they have a high ridership rate.
- All community buses are costly and have low ridership, although the number of services and the hours of operation is very limited. Route 560 & 561 were eliminated, due to very low ridership, on average 7 and 3 passenger per weekdays respectively. They cost $44 and $34 per passenger to operate. Still, line 520/521 and 522 are working ineffectively, with high cost and low ridership.

It is recommended that these community buses also be discontinued. This elimination won't affect the spatial or temporal coverage of the community as their passengers can use other buses that serve the same area.

- Go shuttles also generally costly for YRT, except route 243 (Redstone Go Shuttle).
- Especially route number 203, 204, 242 can be replaced by Ridesourcing service at a lower price. Route number 223 service which covers the area that already being served by route number 44, can be eliminated with no effect on the coverage.
- Among 39 school special routes, only 5 of them cost more than twice ticket price, ranging from $5 to $11 per passenger. Generally, they are better served by publicly owned and operated a bus for safety and security matters.
- No information was available for the cost of operation for route 760 (Vaughan Mills/ Wonderland express bus) that only have 4 stations, although it has a high ridership during the week, especially on weekends.

Comparing the costs that providing DAR services creates for YRT to the cost of similar levels of service using ridesharing programs reveals that out-sourcing on-demand service would benefit YRT financially. In order to provide DAR service by YRT, they have to invest in buying a fleet, paying for employees such as customer service representatives, drivers, and other staff required to manage the schedule. Also, the maintenance of their fleet and facilities creates additional costs over time. Currently, the operation cost for DAR is so high compared to the number of rides provided because it will be charged whether or not anyone uses the system. In contrast, by outsourcing the service, YRT won't face any cost unless residents use the ridesharing service.

4.3.3. Temporal access to transit

For service time coverage, conventional bus service hours and DAR service hours combined. In order to calculate bus service time coverage, 15 minutes waiting time was selected as the normal waiting time for a bus. Table 17 in the appendix shows all the routes with their service time and the frequency of their service. Selected routes from the previous section are collected in Table 15 to show that all the services provided in low-density areas combined can cover a small portion of time, which limits people from their everyday activities and consequently make transit less attractive. This supports the idea that less temporal access to transit will result in less ridership, as we see all these routes experiencing very low ridership rate per trip as well.

By out-sourcing these services to ridesharing companies, people can request a ride at any time, which offers much higher flexibility compared to fix-schedule bus service and more temporal access to transit. In this way, people can use rideshare for the first or last part of their trip and just need to adjust their trip to the main transit line schedule which is frequent and covers long time span during the day, in some place they offer nigh service as well.

Table 15 - Time coverage comparison

Route number	Route name	DAR zone	Covered time (hours per week)		
			DAR	Bus	Total
10	Woodbridge	18	20	35	55
15	Stouffville	19	11	5	16
40	Unionville local	10&8	22:30	35	57:30
41	Markham local	6	19:30	34:45	54:15
52	Holland landing	2	15	27.:45	42:45
58	Mount Albert	1	88	15	103
61	King local	5	21:30	0	21:30
	Sutton-perfferlaw	1	23:30	28:45	52:15
84	Oak Ridge	2	46:30	10	56:30
31	Aurora north	2	25:30	30	55:30
44	Bristol	2	22:30	28	50:30
56	Gorham-Eagle	2	23	29:30	52:30
520/521	Newmarket community bus	2	-	7	7
32	Aurora south	2	25:30	8:45	34:15
50/50A	Queensway	1	99:45	37:30	137:15
51	Keswick local	1	76:15	24:45	101

Source: Authors calculation from YRT schedule (2018)

Also for DAR service, people have to reserve at least one hour before the ride and they don't have the option to make small changes after that. In contrast, when a ride-sharing app such as Uber is used, people can reserve their ride in a shorter time and also have the option to contact the driver. Outsourcing clearly gives people more flexibility compared to other options.

4.3.4. Comfort

Considering physical comfort, DAR and outsourcing offer a similar level of service as they both may use similar type of vehicles. But in terms of ease of use, for most people, ridesharing apps are easy to use and give more real-time information to potential riders. However, those who don't have access to the internet/cell phone, or are unable to learn how to use these apps will have a problem using this service. But for the most part, the widespread availability of mobile internet gives people the option to find direction and book a ride instantly. Although there are some people who are still not able to use these technologies, most people adopt them as a part of their regular life. Studies showed that people would rather use an app to book a ride as it offers flexibility and information about cost and timing. It will be even more attractive when they can communicate with the driver (Clewlow & Mishra, 2017).

Uber, Lyft, Instaryde, and similar ridesharing programs are already working through apps and give people real-time information about the cost, service availability, directions as well as mobile payment. By out-sourcing transit services to these companies, all of these features will be available to riders. Unfortunately, there is no mobile application available for the DAR reservation system offered by YRT yet. Customers must call for information, to make a booking or confirm pick-up time. Bookings must be received and scheduled manually. There isn't an integrated trip planner for the On-Demand trips, so staff must, therefore, confirm the validity of trip locations and service hours manually.

4.3.5. Safety and security, reliability

Fortunately, the low rate of accidents and a high standard of vehicle safety in Canada have led to a high level of safety in transportation, especially in public vehicles (Cheung, Shalaby, Persaud, & Hadayeghi, 2008). For example, in 2016, less than %1 of fatal collision or personal injuries involved buses (Road Safety Research Office, 2017). However, there are some concerns about the safety of other travel modes such as taxicab, ridesharing, and informal transit as they are more involved in accidents compared to bus and rail transit (Rayle et al., 2016; Valenzuela, Schweitzer, & Robles, 2005).

From a security perspective, despite a few incidents, bus and rail transit are still considered as highly secure means of transport (Littman, 2005; Williamson, 2013). Although instant ridesharing platforms (such as Uber) have raised security concerns (Clewlow & Mishra, 2017; Sarriera et al., 2017), studies show that using social media or feedback rating can improve trust and consequently creates more potential for ridesharing by giving drivers and passengers a tool to know each other's (Medeiros, Duarte, Achmad, & Jalali, 2018; Zhou, Huang, Mcglynn, & Han, 2017).

It is expected that drivers who have a contract with YRT will have to pass a more through background check compared to a ridesharing driver, and they would use safer cars. However, in both methods of delivering service, safety and security measures, such as car safety standards and background checks can be regulated and monitored for the sake of riders.

However, the main concern about outsourcing is reliability. How can YRT make sure that the private service providers will be available in a timely manner when there is a request, for example, when it is cold and snowy? There is no commitment that forces the Uber drivers to be available for rides, but if they are dedicated drivers, they have to serve the residents no matter the situation or timing. Autonomous cars will not have this problem but many people are not ready yet to ride in these cars, and they are quite expensive as they are not in the mass production phase yet.

4.4. Conclusion

In this chapter, YRT service was examined based on several performance measures, such as ridership, coverage, and cost. Regarding the last mile issue in low-density areas, two types of situations exist in the York Region. Some of these areas located within city boundaries, and are surrounded by high-frequency transit service but have a very limited transit service and very few people use their transit service. Others are located outside of development clusters and have little or no transit service. The focus of this comparison is mostly on the second type.

Comparing two forms of demand-responsive service in the York region reveals that outsourcing this service to ridesharing companies like Instaryde would benefit the users and the region as well. These benefits includes more flexibility and coverage for the riders and less cost for the provider (YRT). Besides concerns about safety and security measures, outsourcing rides outperform current YRT service (particularly DAR) on providing last-mile service in most parts of York region.

By that, service efficiency will improve as the cost of service will decrease, service area coverage will increase significantly and allow curb-to-curb or curb-to-stop service which increase transit accessibility and rider satisfaction. By connecting more people to transit corridors, and offering a flexible service time, the overall ridership will increase.

5. Conclusion and discussion

5.1. General discussion on urban development and transit accessibility

The most common mode of transportation in suburban and rural areas is the private automobile. It is becoming increasingly evident that traditional public transport services are inefficient to cover the entire range of the population in an effective and affordable way, especially those located in low-density suburban areas. Because the dispersed spatial distribution of land use activities, whether residential, commercial, or industrial influence the mode of transportation and frequency of travel, they are definitely not supporting transit service in low-density areas.

Therefore, transit demand is low and providing regular and frequent service in these areas are inefficient and lower the performance of public transit service providers. Low frequency, limited coverage, and short service span make transit less attractive for residents of these areas and encourages them to use private vehicles for their trips, even the part that is already served by public transit. This creates a negative loop as well.

Besides the negative effect on the environment, there are equity and mobility concerns resulting from less accessible public transit. Using a private vehicle is not an affordable option for many people living in these areas and some are unable to use a car due to their age or health conditions. Studies showed that the benefits provided by transit services in rural and small urban areas are greater than the costs of providing those services. Most of the benefits are generated by creating trips for individuals who would not be able to make a trip if the service were not available. Therefore, from equity standpoints, providing proper last-mile options is necessary for the periphery of urban centers.

Considering that York Region experiencing rapid population growth, and housing prices are increasing in this region, more people will be pushed to the suburban area to save money on housing. York region growth plan already considered urban sprawl as a negative pattern for future development and implemented strategies for dandifying residents near main transit lines to avoid more difficulties in providing transit service for the residents. However, these changes will take long time, and in the meantime we need to find other ways to improve transit accessibility.

For this matter, I have focused on the literature about last-mile or feeder service in low-density areas. I needed to know what the options are and how we can evaluate them. To answer these questions, two literature reviews were conducted as part of this thesis. One for recognizing factors that influence the service providers and users decisions to set up a framework for comparing the options. And the other one for exploring the options for last-mile service in low-density areas.

5.2. Recommendations for improving transit service in low-density areas

Among measures that transit service providers utilize to evaluate their performance, the cost of serving the area and number of people using the service (ridership) are the main indicators. Ridership is related to several factors, including the travel time that it takes to reach high-frequency transit service, including waiting time, spatial accessibility of transit, transit service span, and frequency, cost including fare payment, safety & security, physical comfort, and access to information.

In low-density areas, the main discouraging feature of public transit is the low frequency of services and the limited time of service. Therefore, people have little flexibility to use public transit and they are forced to match their activities to transit availability, which in most case is very limited.

There are several options for improving transit in this matter. In comparing the options we should remember that the effects of any transportation initiative may not affect the population as a whole and can be quite different for each socio-demographic group. Moreover, the size and shape of the service area can strongly influence the quality of the service (Quadrifoglio et al., 2009).

Some of these strategies could be useful for a limited group of people. For example, using a bicycle to reach transit stop/station is not possible for many people due to their general physical ability or occasion of their trip. Likewise, the availability of Park & Ride facilities near transit stations may expedite transit ridership, but only people who have access to a private vehicle can benefit from it. For those who can use these options, first/last mile travel time decreases considerably and they can enjoy the comfort of their car. Although they have to spend money on the car (including gas), they will have more flexibility and accessibility as they connect to the high-frequency transit service directly.

Other strategies such as informal transit, DRT, and out-sourcing rides to private providers are available to every member of society, but they have some issues. For example, regarding informal transit, despite the potential for shortening travel time and increased accessibility by providing service to where public transit won't cover, the issue of safety and security prevents establishing the foundation of this service in Canadian cities. Although in many developing countries this is a normal mode of transportation, it is not common, nor desirable in most developed countries, including Canada.

5.2. Research contribution

As table 8 showed the ratio of people using public transit as the main mode of their commute is not necessarily related to population density. Availability of service, including spatial and temporal coverage and flexibility, has a more profound effect on transit mode share. This result confirms the findings of several other studies mentioned in literature review such as Taylor and Fink (2003).

Timespan and the area that is covered by transit network affect the cost, but it doesn't mean that providing more coverage should necessarily increase the cost for provider. This study shows that by adopting the strategy to the transit demand, not only the service can expand, but also the cost per passenger could decrease.

Based on the studies that showed DAR service could attract people who otherwise might not use transit service by offering them flexibility, even when they have to pay extra money for the service (Davison, Enoch, Ryley, Quddus, & Wang, 2012; Glerum, Atasoy, & Bierlaire, 2014), I have proposed an on-demand service for a wider area in York region compared to current DAR service. But the main difference between the proposed strategy in this research and current practice in YRT is about how this on-demand service will be operated.

Current DAR service is managed by YRT and performed by YRT contractors based on hourly service. This service creates high operating cost whether or not any service is requested because drivers and controller staff are getting paid. This operating cost could be eliminated if these rides are out-sourced to the instant ridesharing companies such as

InstaRyde. This strategy will have a similar structure to what is currently happening in Innisfil (a small town near York Region).

Comparing the cost per passenger for current DAR or bus service in low-density areas showed that if YRT pays the InstaRyde to pick up people from their home and drop them at the nearest high-frequency bus stop, it will cost less than designating staffs to provide DAR service. Also, DAR is less flexible and more limited than InstaRyde service, and if YRT want to expand their DAR service to cover all low-density areas in the York region with a greater service time span, it will definitely cost much more than current cost reported in recent years.

It is worth noting that I used examples of ridesharing companies just to demonstrate the possibilities and compare the cost in a real case. Some of these companies may not have a good reputation as increasing financial benefit might be more important for them than servicing public. However, public transit authorities can use the model of instant ridesharing in providing on-demand service and not necessarily have contract with the named companies. A similar result was reported in Talley and Anderson (1986) study.

Currently, DRT service is performed by public transit service providers, and they have higher standards for maintenance and hiring drivers, people have a better perception regarding the safety and security of this service. However, in most cases, public transit entities have a contract with smaller companies to provide staff and maintain their fleet, including bus and on-demand service. So, in reality, they are already contracting out their supply side.

However, the main difference between DRT and out-sourcing rides is the commitment to providing service. When a public transit company (e.g. YRT) is responsible, the service will be provided based on the schedule and drivers receive a salary based on hours, and they will the designated service regardless of weather, personal preference, or any other issue. But there is considerably less commitment in case of out-sourcing the rider. For example, when Uber drivers are responsible for serving an area, there is a high possibility that no drivers willing to offer a ride in snowy days, therefore the system would be less reliable for riders.

In the case of the York region case study, ridesourcing (i.e. contracting out part of transit service) can enhance the transit service in two major ways: replacing underutilized routes to improve operational efficiency and extend transit coverage to the low-density areas. Transit coverage (both geographic coverage and time span) can increase considerably by outsourcing transit rides in low demand areas to an instant ride-hailing company.

Besides coverage, outsourcing service has an advantage over DAR service in York Region considering the cost of YRT services. From a financial perspective, outsourcing transit service would benefit public transit authorities by eliminating capital investment in buying fleets. Moreover, they don't have to employ customer service representatives, drivers, and other staff required to manage the schedule and take care of fleet maintenance. All these hassles and their operation cost will be eliminated when YRT contract out the service. Assuming that, people want to use outsourcing service traveling from the furthest point in each zone to the high-frequency transit service, fare comparison shows that DAR cost more for YRT compare to compensating to an instant ride-hailing company (e.g. Uber, Lyft, and InstaRyde).

By adding the out-sourcing option, the whole low demand area will have full coverage as anyone has access to curb-to-stop service at any time, although in reality there might not be any individual driver willing to work at some point.

5.3. Opportunities for further studies and research limitation

This research provided an overview of the current situation of a case study that already utilized different options for last-mile service. However, for a better comparison and tailoring the service for each area, access to detailed ridership could be very beneficial. These data would show how many people already use transit in each stop, which creates a more accurate picture of current transit demand.

This study concluded that outsourcing transit rides to dynamic ride-sharing company can lower the cost of transit service in low demand areas, while offers a high level of flexibility to the transit service, with small or no extra charge for riders, brings them comfort and save their time. Although people still have safety concerns in this matter, due to mandatory regulations and screening process for drivers, this mode of transit perceived safer and more secure than informal transit. The widespread use of companies like Uber and Lyft among Canadians shows the level of trust is high enough among residents to consider them as a desirable option.

However, the issue of reliability still plays an important role in transit providers' decision-making process. Unless there is a solid legal support for securing the reliability of their service, these private entities cannot be considered as a viable option. However, due to limited knowledge of the author and focus of this project, despite their vital role, legal and legislative issues were not discussed in this research. I believe planners with more knowledge about legal issues can take this work further to become more practical.

Moreover, as Talley and Anderson (1986) discussed the issue of transit employee working hours, shift structure and overtime payment, transit authorities should adjust their commitment to the employee's union requirement. Although they suggest that outsourcing can release some pressure off the provider's side, this issue should be discussed in more detail in further studies.

As a general point of improvement, I believe detailed data about the number of cars in each family could help in predicting the number of potential users. Although many people living in the study area already acquired a car, they might consider using public transit if they have access to a flexible service which cost them less than using their own car.

To plan for a better service, accessibility measurement should become more realistic. For example, when there are only a few rides in a limited time, most probably many people won't use them because they eventually need to have a private car and have to pay for the insurance and car expense. Just having a transit stop that a bus will come a few times a day is not good enough access to transit to attract riders. So the main objective could be discouraging people from getting a car for every adult in the family. Therefore, through accessibility, we should be able to measure how well an area is served. There are some studies that redefined accessibility and measured it with more precise indicators, however, their methods were not used in policy-making due to the complicated formulation.

Finally, the result of similar projects, such as Innisfil which contracted ride-hailing companies (e.g. Uber) can help planners to create a more realistic plan to evaluate the reliability of service and other shortcomings of this strategy.

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Appendices

Table 15 - Ridership and provider's cost for selected routes

Route number	Total cost per hour (including staff cost)	Net cost per passenger September 2017				Average boarding December 2016			Average number of passenger per trip		
		Weekday rush hour	Weekday non-rush hour	Saturday	Sunday	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
7		3	6	13	-	741	114	-	12.35	3.25	-
10		4	7	-	-	252	-	-	4.67	-	-
14		4	11	-	-	408	-	-	7.4	-	-
15		27	-	-	-	22	-	-	1.47	-	-
26		4	7	6	13	493	105	85	5.93	3.28	2.65
28		18	-	-	-	53	-	-	2.94	-	-
31		8	-	-	-	75	-	-	5.36	-	-
32		5	7	-	-	424	-	-	8.31	-	-
40		4	8	11	14	369	101	77	7.53	3.88	3.21
41		6	9	7	11	188	76	52	4.09	3.17	2.17
44		9	14	23	-	104	52	-	5.20	4.33	-
50		3	6	5	4	1053	528	941	21.06	14.27	37.64
51		17	35	27	-	110	26	-	2.89	1.44	-
52		10	10	9	-	185	94	-	4.74	4.27	-
55/55B		8.5	8	18	18	279	102	109	4.89	1.79	2.27
56		8	6	6	12	309	116	518	8.13	4.83	23.55
58		27	28	-	-	70	-	-	2.92		
84		12	-	-	-	77		-	4.81		

Table 16 continued - Ridership and provider's cost for selected routes

Route number	Total cost per hour (including staff cost)	Net cost per passenger September 2017				Average boarding December 2016			Average passenger per trip		
		Weekday rush hour	Weekday non-rush hour	Saturday	Sunday	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
242		21	-	-	-	25	-	-	3.31	-	-
320		45	-	-	-	27	-	-	3.38	-	-
520/521		-	19	25	38	90	44	65	11.25	11	16.25
522		-	18	22	-	103	57	-	7.92	4.38	-
589/590		-	16	23	24	148	148	90	13.45	13.45	8.18
10 DAR	41.3	-	-	101	101		7	7			
15 DAR	64.7	-	-	102	206		3	3			
31/32/84 DAR	35.6	-	27	28	-		7				
40 DAR	41.3	-	49	166	-						
41 DAR	41.3	-	42	133	-						
44 DAR	81.5	-	82	76	-						
50A DAR		-	-	114	161						
52 DAR	41.3	-	26	28							
56 DAR	119.1	-	91	45	91						
58 DAR	41.3	-	32	24	-		10				
61 DAR	100.6	26	-	-	-	6					
84 DAR	38.8	-	25		-						
DAR North	35.3	-	47	-	-						

Source: York Region Committee of the Whole Transportation Services (2018)

Table 16 - YRT service hours

Route number	Hours of service			Number of services (Both sides combined)		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
7	5:15 a.m.-11:56 p.m.	8 a.m.-11 p.m.	-	60	35	-
10	6 a.m.-10:45 p.m.	-	-	54	-	-
10 DAR	-	10 a.m.-7:45 p.m.	9:30 a.m.-7:45 p.m.	-	-	-
14	5:20 a.m.-9 p.m.	-	-	55	-	-
15	6 a.m.-10 a.m. 3 p.m.-7:30	-	-	15	-	-
15 DAR	-	7a.m.-9:45 a.m. 3 p.m. – 5:45 pm	8 a.m.-10:45 a.m. 3 p.m. – 5:45 pm	-	-	-
26	5 a.m. – 8:45 p.m.	9 a.m.- 8 p.m.	9 a.m. -8:15 p.m.	83	32	32
28	5 a.m.-8:30 a.m. 3 p.m.-7:30 p.m.	-	-	18	-	-
31	5:45 a.m.-9:15 a.m. 2:45 p.m.-7:05 p.m.	-	-	14	-	-
31DAR	6:30 p.m.-10:45 p.m.	-	-	-	-	-
32	5:10 a.m.-7:30 p.m.	-	-	51	-	-
32 DAR	6:30 p.m.-10:45 p.m.	7 a.m.-6:45 p.m.	-	-	-	-
40	6 a.m.-8:30 p.m.	8 a.m.-8:45 p.m.	9:30 a.m.-9:30 p.m.	49	26	24
40 DAR	8:15 p.m.-10:45 p.m.	8:15 p.m.-10:45 p.m.	-	-	-	-
41	5:45 a.m.-7:45 p.m.	8:15 a.m.-8 p.m.	8:30 a.m.-8:10 p.m.	46	24	24

Table 17 continued - YRT service hour

Route number	Hours of service			Number of services (Both sides combined)		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
41 DAR	7:30 p.m.-10:45 p.m.	7:30 p.m.-10:45 p.m.	-	-	-	-
44	5 a.m. – 7:30 pm	7 a.m.-6:30p.m.	-	20	12	-
44 DAR	7 p.m. – 10:45 pm	7 p.m. – 10:45 pm	-	-	-	-
50	4 a.m.-11:50 p.m.	6 a.m.-11:30 p.m.	6 a.m.-11:45 p.m.	50	37	25
50A DAR	7:30 a.m.-10:45 p.m.	8 a.m.-7:45 p.m.	8 a.m.-7:45 p.m.	-	-	-
51	5 a.m. – 10 p.m.	9 a.m. – 9 p.m.	-	38	18	-
52	5:15 a.m.-8 p.m.	8 a.m.-7 p.m.	-	39	22	-
52 DAR	7:30 a.m. – 10:45 p.m.	7 p.m.-10:45 p.m.	7 p.m.-10:45 p.m.	-	-	-
55/55B	5:30 a.m.-12:30 a.m.	5 a.m.-12:30 a.m.	8 a.m. – 12:30 a.m.	57	57	48
56	6 a.m.-7:15 p.m.	7 a.m.-7 p.m.	8 a.m.-7 p.m.	38	24	22
56 DAR	7 p.m.-10:45 p.m.	7 p.m.-9:15 p.m.	7 p.m.-9:15 p.m.	-	-	-
58	5:20 a.m.-8:20 p.m.	-	-	24	-	-
58 DAR	10:30 p.m. -10:45 p.m.	8 a.m. – 7:45 p.m.	-	-	-	-
61 DAR	5:30 a.m.- 7:50 a.m. 5:30 p.m.-7:30 p.m.	-	-	-	-	-
84	5:20 a.m.-9:30 a.m. 2:20 p.m.-6:30 p.m.	-	-	16	-	-

Table 17 continued - YRT service hour

Route number	Hours of service			Number of services (Both sides combined)		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
84 DAR	9:30 a.m.-1:45 p.m. 6:30 p.m.-10:45 p.m.	7 a.m.-6:45 p.m.	-	-	-	-
203	5:50 a.m.-8:05 a.m. 5 p.m.-7:50 p.m.	-	-	8	-	-
204	5:10 p.m.-7:30 p.m.	-	-	7	-	-
223	5:36 a.m.- 7:25 a.m. 4:45 p.m.-7:35 p.m.	-	-	11	-	-
242	6 a.m.-7:45 a.m. 5:30 p.m.- 7:15 p.m.	-	-	8	-	-
320	6 a.m.- 8:30 a.m. 4:40 p.m.-7 p.m.	-	-	8	-	-
520	9 a.m.-5 p.m.	9 a.m.-5 p.m.	9 a.m.-5 p.m.	4	4	4
521	9 a.m.-5 p.m.	-	-	4	-	-
522	9 a.m.-5:30 p.m.	9 a.m.-5:30 p.m.	-	13	13	-
589/590	9 a.m. – 6 p.m.	9 a.m. – 6 p.m.	9 a.m. – 6 p.m.	11	11	11
DAR North	7:30 a.m. – 10:45 p.m.	-	-	-	-	-

Source: YRT schedule, (2018)

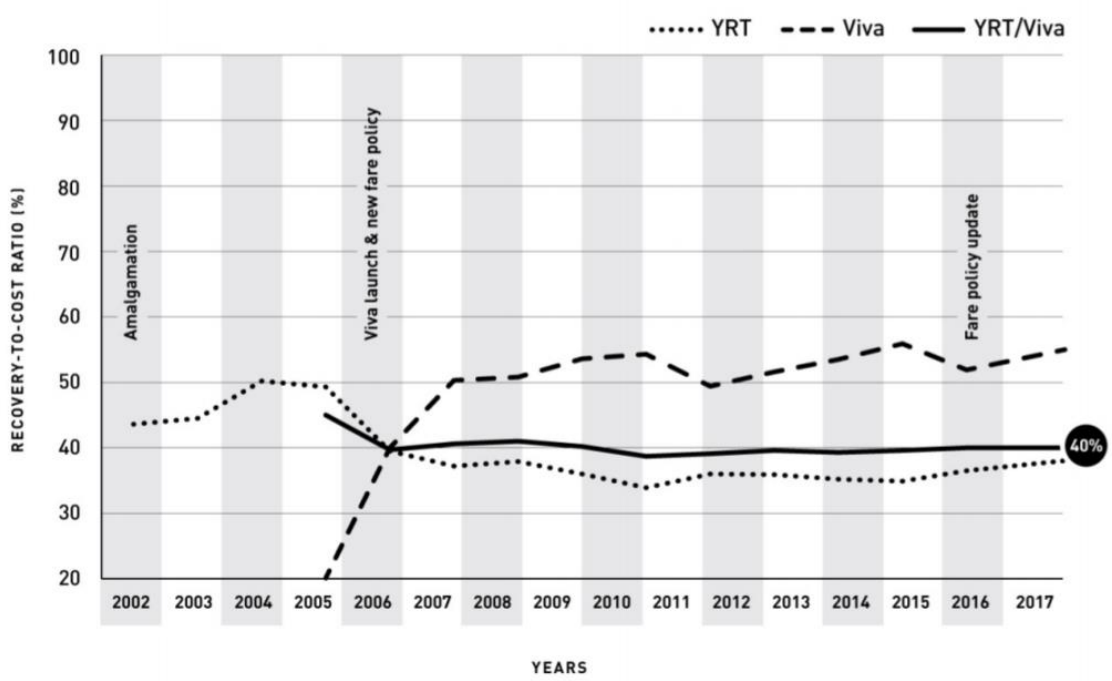

Figure 10 - Revenue to cost ratio trends

Source: York Region Committee of the Whole Transportation Services (2018) pp.6

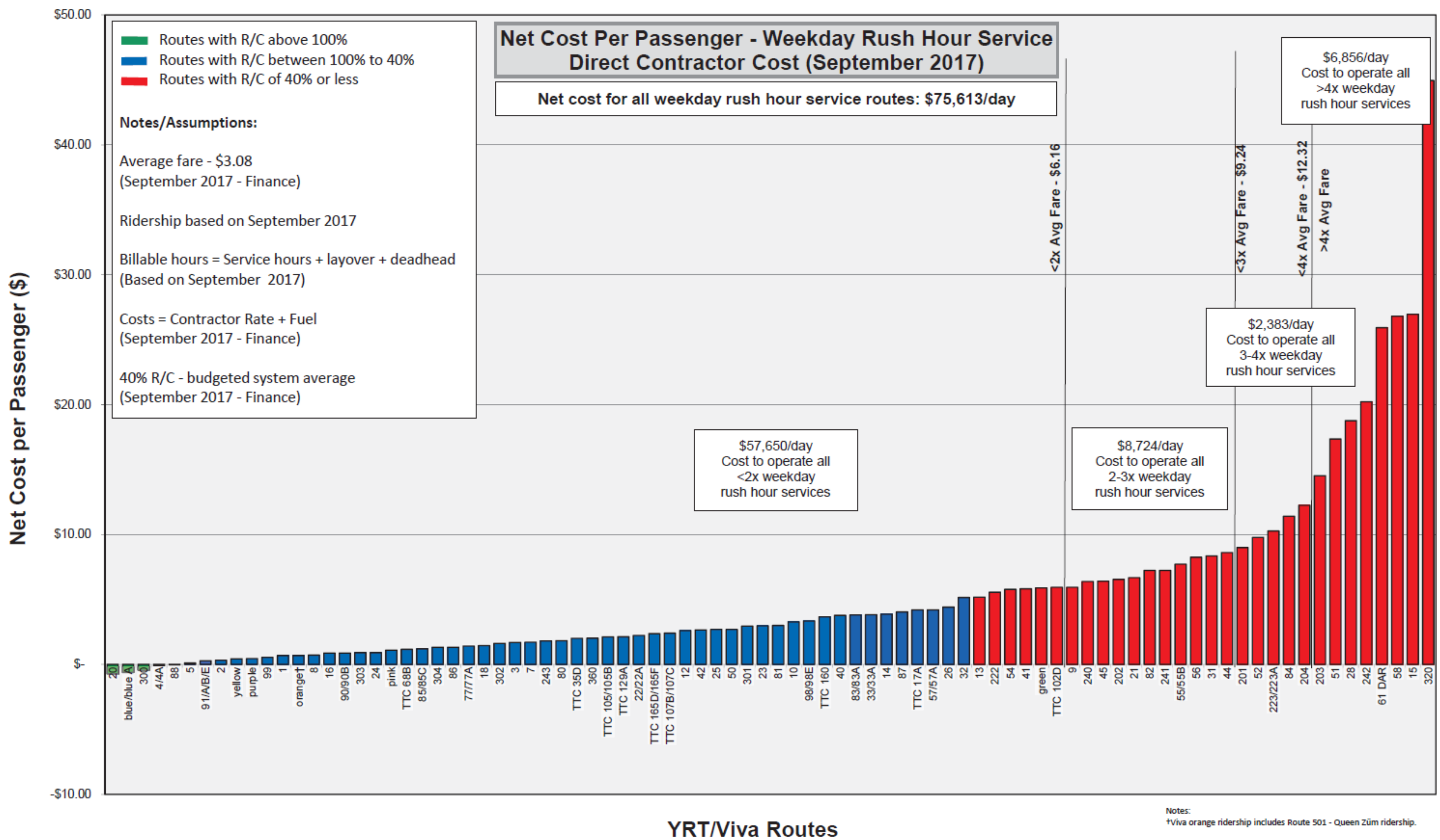

Figure 91 - YRT Net Cost per Passenger - Weekday Rush Hour

Source: York Region Committee of the Whole Transportation Services (2018)

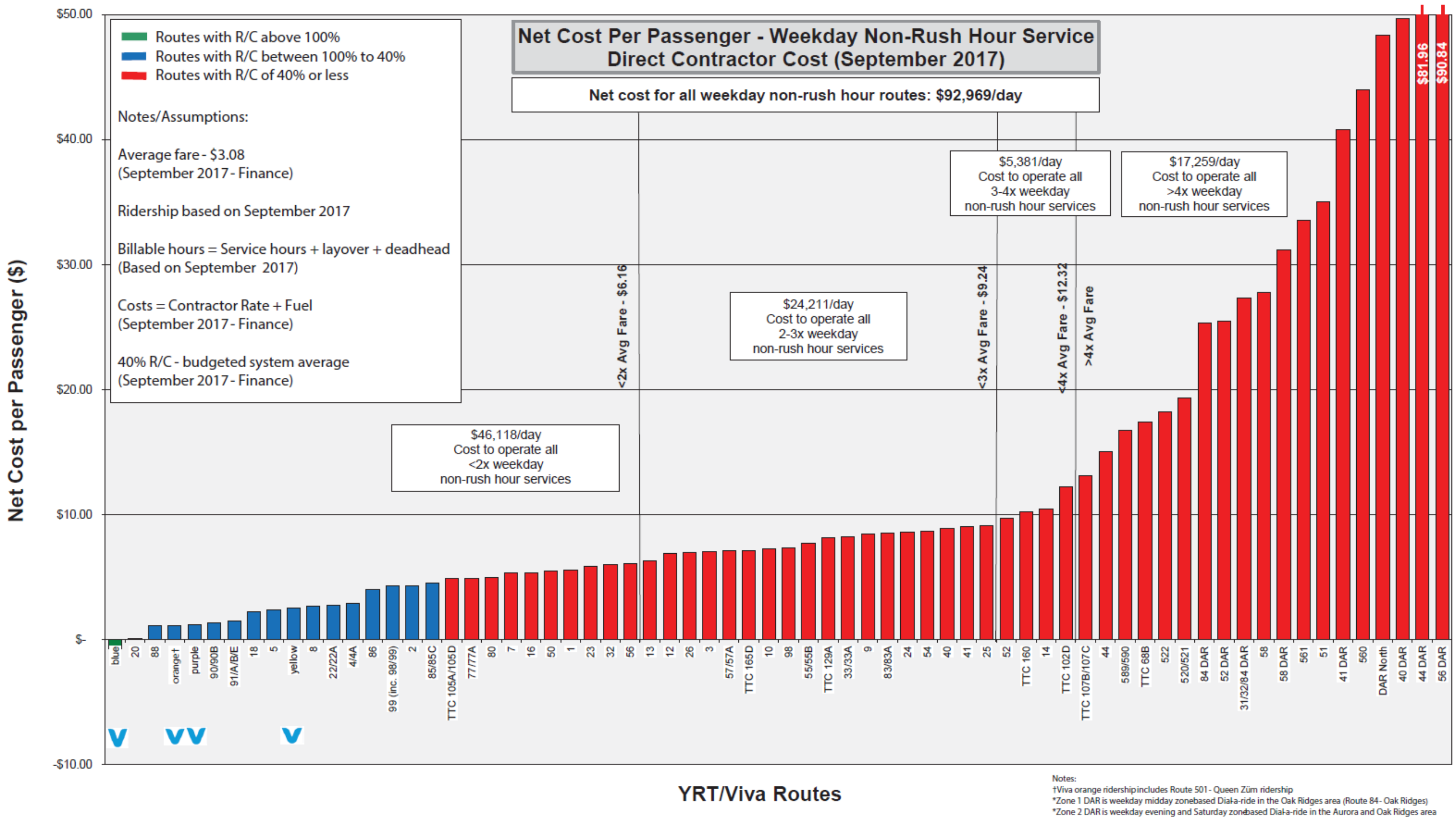

Figure 102 - YRT Net Cost per Passenger - Weekday Non-Rush Hour

Source: York Region Committee of the Whole Transportation Services (2018)

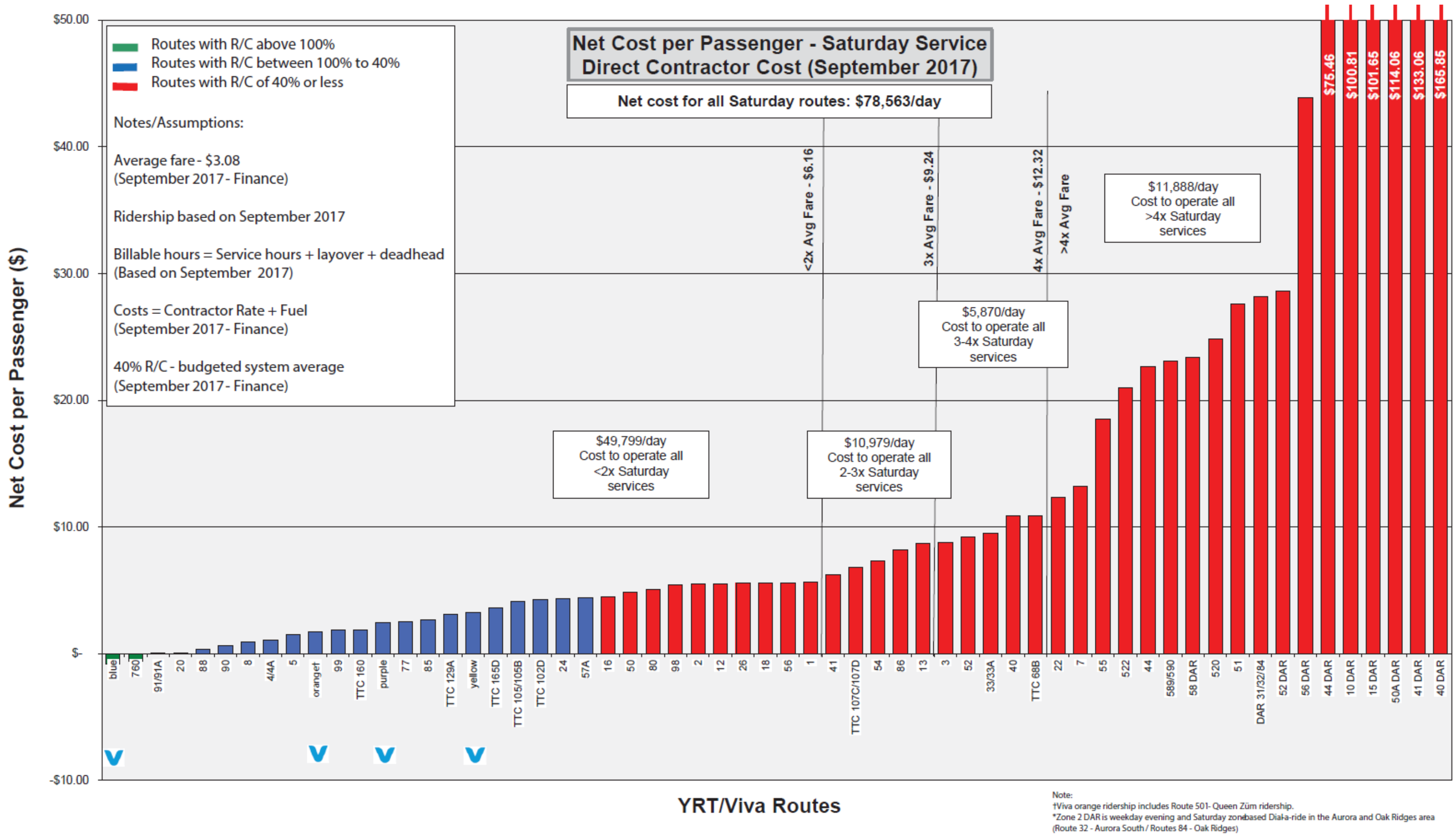

Figure 113 - YRT Net Cost per Passenger - Saturday

Source: York Region Committee of the Whole Transportation Services (2018)

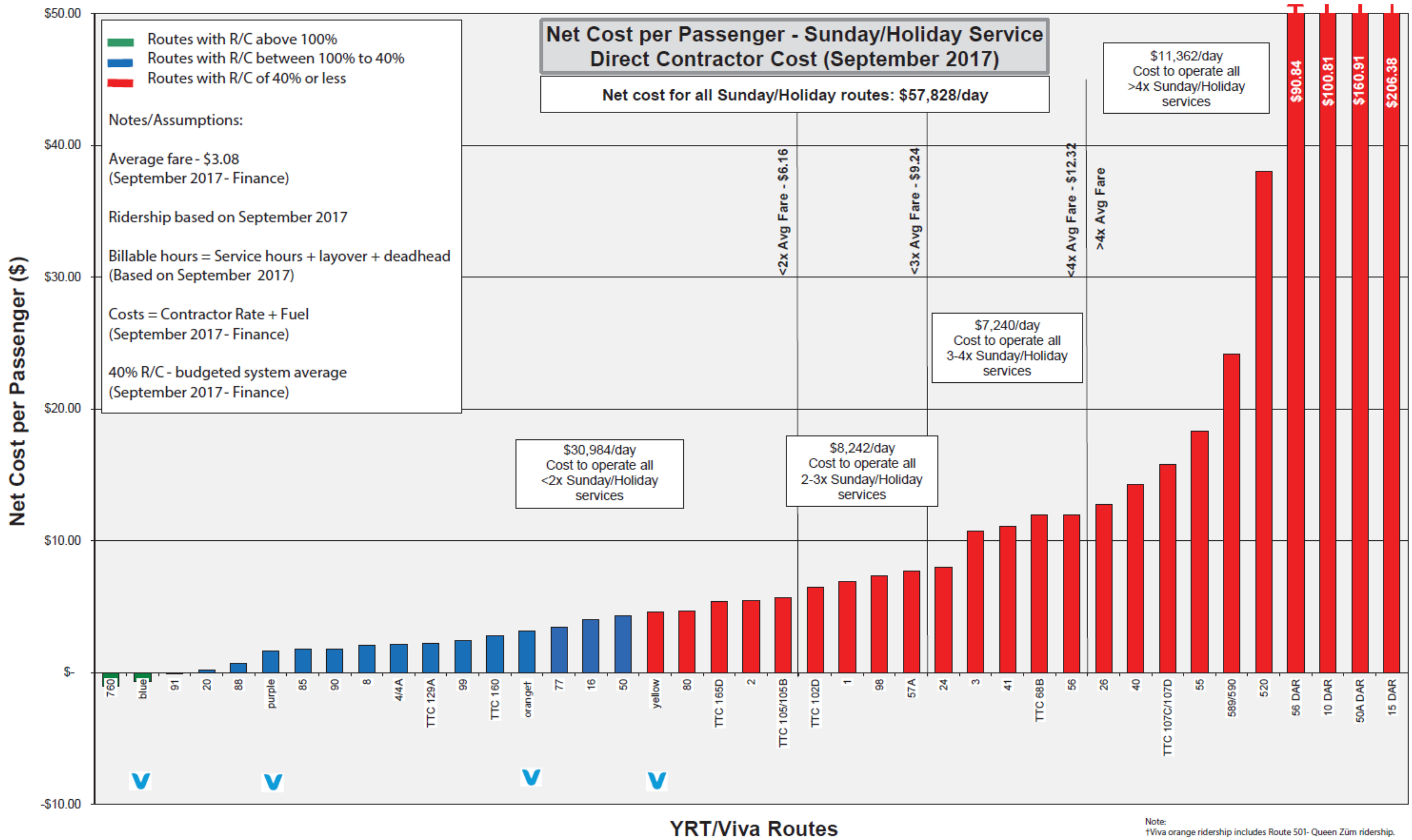

Figure 124 - YRT Net Cost per Passenger - Sunday

Source: York Region Committee of the Whole Transportation Services (2018)