

Final Masters Project

Bus Rapid Transit or Light Rail to Move Ontario Forward

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EXECUTIVE SUMMARY

INTRODUCTION

Increasing need for public transit places demands on existing public transit service providers, who must manage the pressure of additional operating requirements and the need to replace aging infrastructure. Cities often rely on investments from both the provincial and federal government to help tackle the cost of expansion, as it often far exceeds the revenue generated from providing transit services.

Many Canadian cities have developed plans for implementing rapid transit systems as a means of improving existing service levels and easing congestion. These plans often focus on bus rapid transit (BRT) or light rail transit (LRT) as the transit technology of choice; however, both are largely debated and there is not a clear distinction between the superiority of one mode over the other.

In 2015, the Ontario government passed the *Building Ontario Up Act, 2015*, enabling the largest transit infrastructure investment in the history of the Greater Toronto and Hamilton Area (GTHA). The immediate future will see strategic investments in priority rapid transit projects, either BRT or LRT, which will aim to connect other transit systems across the GTHA and improve inter-regional connectivity while ensuring value for money.

This report aims to provide a comparative assessment of BRT and LRT systems with the goal of identifying which rapid transit technology should be used to improve interregional connectivity and demonstrate stewardship of resources. Specifically, this report will serve to provide an assessment of economic, technical, environmental and social considerations of BRT and LRT systems, providing a fulsome understanding of both transit technologies. This research project was sponsored by the Treasury Board Secretariat (TBS), a central agency in the government of Ontario. TBS is responsible for planning, expenditure management and providing approval of transit investment proposals put forward by line ministries and agencies.

METHODS

An integrated multi-methods research strategy was developed to provide a comparative assessment of bus rapid transit (BRT) and light rail transit (LRT) which included a literature review, key informant interviews, and a passenger preference survey. This research approach allowed for the comprehensive understanding of two choice rapid transit technologies. The literature review aimed to provide the initial assessment of BRT and LRT systems as well as jurisdictional information to serve as benchmark comparators. The key informant interviews aimed to supplement the literature based research through information provided by professionals working in the Canadian public transit industry. Lastly, the passenger preference survey aimed to measure a sample population of public transit user's social perception and preference of BRT and LRT systems. The

analysis of the research focused on an inductive approach, as the goal was to develop a comparative assessment without the application of theory to direct the collection of data.

THEORETICAL FRAMEWORK

The theory relating to this study is based on New Public Management (NPM), specifically gaining the most value from tax-payer dollars and demonstrating stewardship of resources. To ensure financial sustainability, governments have placed a premium on leveraging value from tax-payer dollars. This has crossed many public policy arenas such as health, education and public transportation and falls under the rubric of NPM. With the constant pressure from competing sectors (health, education, law) it is important for the government to invest in public transit that will deliver tangible societal benefits in the most efficient and sustainable manner.

FINDINGS

Several themes emerged from the research on both BRT and LRT systems and included:

- The capital cost of building a LRT system typically exceeds BRT systems due to their heavier infrastructure requirements such as dedicated rails and overhead catenary;
- BRT systems are more cost efficient to operate and maintain, up to a ridership threshold point of approximately 5000 passengers per direction per hour. Ridership exceeding this volume is better served with LRT technology due to a higher passenger carrying capacity;
- BRT systems better support interregional connectivity as they are not fixed to track, providing for more network flexibility;
- Through proper integration and planning, both systems can leverage the economic benefits of transit oriented development;
- Safety is largely a function of overall system design; however, increased automation on LRT systems contributes to safer operations;
- Both systems can be environmentally efficient, depending on the power source of the vehicle and mode shift; and
- LRT is the preferred mode of public transit with BRT systems carrying a negative social perception of poor value and service, associated with traditional bus public transit.

RECOMMENDATIONS AND CONCLUSION

The outcome of the research led to three options for consideration to improve interregional connectivity while demonstrating fiscal responsibility:

- 1) Build only BRT systems;
- 2) Build only LRT systems; and
- 3) Build both BRT and LRT systems.

These options were assessed against the intended government objectives and it was recommended that a combination of both BRT and LRT systems be built across the GTHA to improve interregional connectivity while demonstrating value for money. Building both rapid transit systems allows for targeted infrastructure investments where they are required, maximizing transit development across the region. With such diversity across the GTHA, one rapid transit mode is not better suited over the other to achieve program objectives. LRT systems can be built in areas where urban density supports the ridership and larger infrastructure investment, while more cost efficient BRT systems can be constructed in larger, less densely populated suburban areas.

It is also recommended ridership projections for the proposed corridor are taken into consideration when selecting the rapid transit technology. If projected ridership is estimated to exceed 5000 passengers per hour, per direction, it is recommended that LRT technology be considered, due to the available capacity to support this ridership and potential for realized cost efficiencies. If ridership is below this threshold, it is recommended BRT technology be considered.

Building both systems will support value for money through an optimized balance of cost, economic considerations, passenger carrying capacity, safety, environmental efficiency, and social preference.

This research aimed to provide a comparative assessment on the benefits and consideration for selecting of both BRT and LRT technology. Strategic decisions regarding the appropriate mode of transit are required to ensure stewardship of resources and a long-term sustainable public transit system in the GTHA.

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1.0 INTRODUCTION

Canadian transit ridership has increased by more than 10% in the first half of this decade (Canadian Urban Transit Association, 2007, p.1). This has placed increased demand on transit systems which must manage the pressure of additional operating requirements and the need to replace aging infrastructure. Cities across the country rely on investments from the provincial and federal levels of government to help tackle congestion, air pollution and economic growth as the cost of operating and expansion is beyond the capacity of transit fare revenue (Ruffilli, 2010, para. 4).

In recent years, many Canadian cities have developed plans for the implementation of rapid transit systems as a means of improving existing service levels and easing congestion. Ruffilli (2010) notes these plans often focus on bus rapid transit (BRT) or light rail transit (LRT) as the transit technology of choice for increasing ridership; however, both methods are largely debated and contested as being more favourable. Tirachini, Hensher and Jara-Diaz (2010) highlight the choice between BRT and LRT systems is a key decision in urban transportation policy when deciding to provide service in a particular corridor.

Rapid transit projects are implemented as a means of improving public transit and interconnectivity as riders can benefit from faster, more reliable service. Vehicles are often larger, meaning they can carry more passengers and travel in dedicated lanes, usually in the form of a bus or a light rail vehicle (“What’s Rapid Transit”?, n.d.). The implementation of BRT or LRT systems will be critical for governments to achieve stated transportation objectives and for the transit industry to meet ridership targets. Laporte, Mesa, Ortega and Perea (2011) note the main objective of a rapid transit system is to improve the population’s mobility, providing fast travel times to many people while respecting technical and budgetary constraints.

In 2015, the Ontario government passed the *Building Ontario Up Act, 2015*, enabling the largest infrastructure investment in Ontario history (Government of Ontario, 2015). Through the enabling legislation, the Moving Ontario Forward initiative was created, dedicating more than \$15 billion over 10 years, for public transportation related initiatives inside the Greater Toronto and Hamilton Area (GTHA).

The immediate future will see strategic investments in priority rapid transit projects, which will aim to connect other municipal transit systems across the GTHA to the regional commuter rail network (Office of the Premier, 2015). Rapid transit investments will be made in different modes, including BRT and LRT projects.

This paper seeks to conduct a comparative assessment of BRT and LRT systems for the government of Ontario's Treasury Board Secretariat (TBS herein), specifically the Planning and Expenditure Management Unit (PEMU).

TBS is the central agency of the government of Ontario responsible for planning, expenditure management and controllership, through decisions made by the Minister of Treasury Board and the elected Members of Provincial Parliament, who form the Treasury Board. TBS has an aggressive mandate to strengthen accountability, openness, and modernization while ensuring value for money as a top priority.

All transit infrastructure projects greater than \$10 million must obtain Treasury Board approval through Ministry capital plans and Treasury Board Submission prior to the commencement of design, procurement and construction (Treasury Board Secretariat, 2015).

Within TBS, PEMU is the area responsible for providing expenditure analysis and business decision-making recommendations, on project proposals relating to investments in public transit infrastructure. Investment proposal analysis on Treasury Board Submissions and Ministry Capital Plans is conducted to provide an informed recommendation of the proposed project to the Minister of Treasury Board and elected Board members prior to the project receiving approval.

FIGURE 1: THE GREATER TORONTO AND HAMILTON AREA

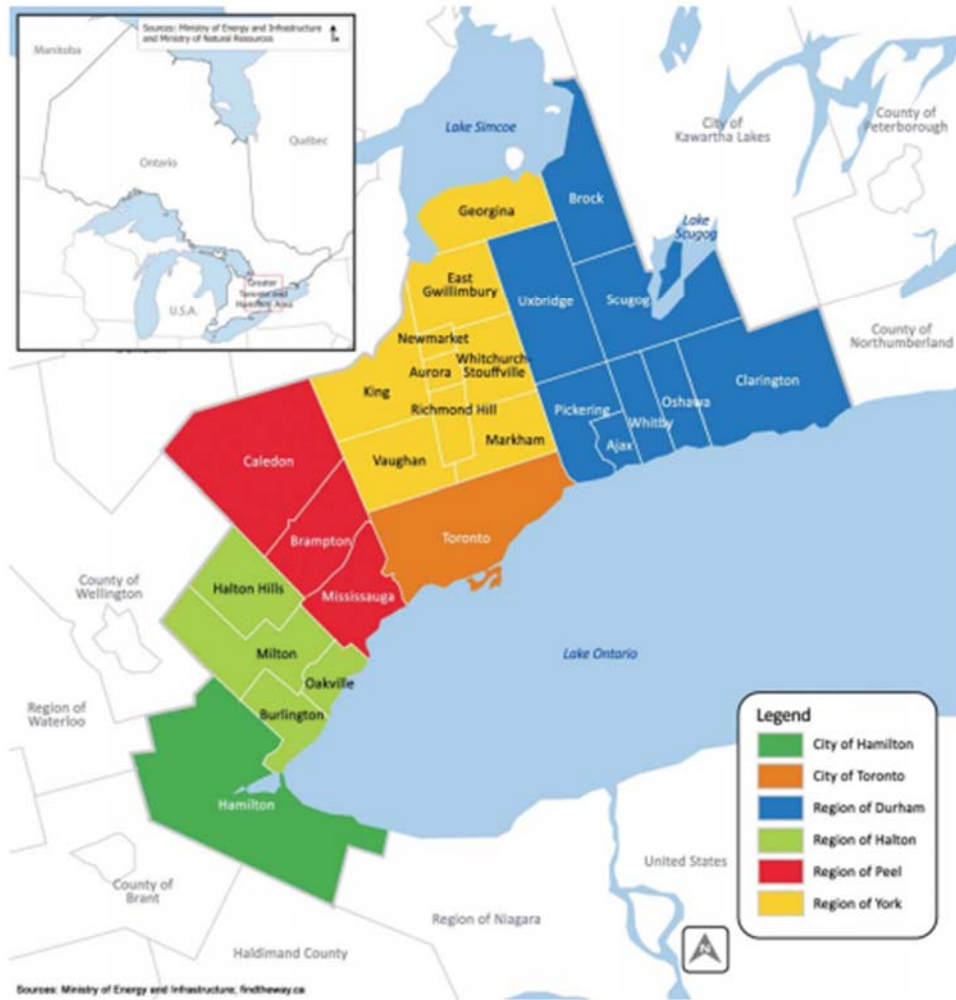


FIGURE 1: MAP OF GREATER TORONTO AND HAMILTON AREA. METROLINX (2008).

1.2 PROJECT PROBLEM

Given the substantial public commitment to infrastructure spending over the next 10 years, TBS will see an increased number of large-scale capital transit proposals requiring Treasury Board approval.

Portfolio teams within TBS responsible for the analysis and recommendation of transit proposals often do not have specific knowledge of the analysis criteria for BRT and LRT technologies modes. As such, TBS staff and division managers often rely on other areas of government to provide this analysis and advice. Staff are also relied upon by other areas of government, including members of the Premiers Office, Deputy Ministers Office and Cabinet Office, to provide briefings on the transit technology proposed in advance of formal Treasury

Board sessions. Due to the unfamiliarity of transit technologies, a challenge arises when staff are asked to provide information on the fiscal, environmental, social and technical aspects of BRT and LRT systems.

Specific knowledge of BRT and LRT modes is required, to provide informed recommendations to Treasury Board regarding the type of transit that would maximize the economic, environmental and social benefits for a particular community, while remaining fiscally responsible.

1.3 PROJECT OBJECTIVES AND QUESTION

The primary research question is an investigation into the strengths and weaknesses of BRT and LRT transportation systems, in an effort to determine which mode might best support inter-regional connectivity and value for money, a primary goal of the Moving Ontario Forward initiative. Sub research questions which will be addressed under this topic include:

- Which system is more cost efficient to build, operate and maintain;
- Which system best leverages transit oriented development;
- What systems can carry the most passengers and reduce journey times;
- What is the social perception of BRT and LRT systems;
- Which system is more environmentally friendly; and
- What design features contribute to the success of BRT or LRT.

The significance of this project is to provide a comprehensive comparative analysis report outlining the strengths and weaknesses of both BRT and LRT systems based on the above mentioned criteria. Data on the measurement criteria from other jurisdictions who have implemented BRT and LRT systems will be used to supplement the research findings in this report. This information will be used to assist in the facilitation of decision-making by TBS staff, on large transit infrastructure proposals.

Once complete, the report will aim to provide a comparative assessment of both transit systems technologies, using current literature on transportation planning and data obtained from primary research. This assessment will aim to provide recommendations to TBS on which transportation method is more appropriate given the need to remain fiscally responsible while delivering the transportation agenda.

1.4 BACKGROUND

Rapid Transit

Rapid transit projects are implemented with the goal of moving a large number of people at the same time and at higher speeds, using either light rail trains or buses as the mode of transit. Ruffilli (2010) notes rapid transit can be defined as a transit service which is separated partially

or completely from general traffic, and thus able to achieve higher levels of speed, reliability and vehicle productivity, compared to those transit methods operating in mixed traffic.

Both BRT and LRT systems can be defined as rapid transit, as each mode allows for the rapid movement of people; however, both systems vary largely in the technology used, infrastructure requirements needed to support the network, and size suitability (Ruffilli, 2010, p. 2). Dedicated lanes of traffic are restricted for use only by BRT or LRT systems and allow for faster travel, resulting in the movement of more people at higher speeds.

The benefits of rapid transit can extend beyond the vehicles and dedicated lanes. “What’s Rapid Transit”? (n.d., para. 5) identifies rapid transit as a combination of elements which include stations, fare collection systems, and smart technologies. These systems are said to make the transit system faster to access and enhance the passenger experience.

Light Rail Transit

LRT systems have similar components to that of a subway or streetcar, as the vehicle operates on a set of tracks, above or below ground. However, there are many distinguishing factors that separate LRT vehicles from other forms of track operated public transit modes. Black (1993) notes that light rail is a form of urban transportation, using electronically propelled rail vehicles, operating as a single unit or as a multiple vehicle train, on dedicated lanes of track separate from vehicular traffic.

System and infrastructure requirements, such as urban integration and station design, also set LRT apart from other public transit modes. The Toronto Environmental Alliance (2008) notes other distinguishing LRT features include:

- Vehicles are larger than streetcars, but smaller than subways;
- Vehicles are powered by an overhead or underground electricity source; and
- Passengers have multiple ground level entry and exit points along the vehicle.

Bus Rapid Transit

BRT systems are rubber-tired modes of public transit operating on public roadways, which utilize buses as the method of carrying passengers. Mackechnie (2014) notes BRT technology is a system of uniquely designed buses that operate more like conventional rail, compared to traditional local buses, operating in dedicated lanes or reserved bus routes, separate from traffic. To closer align with rail technology, BRT routes are often branded differently from regular buses. Additionally, BRT vehicles are designed to have larger windows, ground level boarding, bigger stations, enhanced modern features as well as a route naming convention

which resembles subway-style nomenclature, instead of bus route numbers (Mackechnie, 2014, para.2).

1.5 ORGANIZATION OF THIS REPORT

The remaining portion of this report proceeds as follows: Section 2 outlines the methods used in this research study and identifies the strengths and weaknesses of the methodology. Section 3 provides the theoretical framework which serves to demonstrate the structure supporting this research. Section 4 reviews the literature on the economic, technical, environmental and social considerations of BRT and LRT technology and section 5 summarizes the findings from the key informant interviews and passenger preference survey. Section 6 provides a discussion and analysis on the key research findings, followed by section 7, which outlines options for consideration. The final sections of the report provide recommendations for the TBS and concluding remarks.

2.0 METHODOLOGY

The approach of this paper will be a strategic comparative assessment of both BRT and LRT systems. The research required for the comparative assessment was obtained through a multi-methods study. A multi-methods design allows for the comprehensive gaining of knowledge about different aspects of a phenomenon, and therefore provides for a more complete explanation of a topic (Gil-Garcia & Pardo, 2006, p. 5).

The comparative assessment relied on both qualitative and quantitative information as a means of drawing conclusions about the data. Qualitative information about BRT and LRT systems was explored through relevant literature and key informant interviews. Quantitative information was also gained through a passenger preference survey, which provided a measurement of the social preference of BRT and LRT systems.

Qualitative information assisted to describe the strengths and weaknesses of each transit analysis criteria, and quantitative data provided insight into passenger preference regarding BRT and LRT systems. This multi-method approach best addressed the research question as it supported two independent research observations in one project and allowed for the results to be triangulated to form a complete analysis of both transit systems.

The following section of the report outlines each of the methods used in this research project, the analysis criteria for public transit projects, and concludes with a discussion on the strengths and weaknesses of this methodology.

Criteria for Transit Mode Analysis

The criteria for evaluating both BRT and LRT technologies included the analysis of economic, technical, environmental and social factors. Specifically, economic factors included the opportunity for land use development and the capital, operating and maintenance cost of implementation; technical features included speed, capacity design and safety; environmental efficiency of the transit technologies and social factors were examined through passenger preference.

The measurement criteria for BRT and LRT systems is based on the transit project analysis methodology of multiple criteria decision making/aiding (MCDM/A). Zak (2011) notes MCDM/A involves multiple parameters for decision making and is a useful tool for the analysis, evaluation and optimization of public transit proposals.

This methodology supports a comparative assessment of both transit technologies, as it provides the framework for analyzing mass transit projects. Zak (2011) notes public transit projects involve many complex operations with important impacts to various stakeholder

groups as such, transit projects should undergo a comprehensive analysis of economic, technical, social and environmental criteria (p. 2).

Literature Review

The goal of the literature review was to provide the initial assessment and understanding of both BRT and LRT systems, using the MCDM/A criteria. The literature review provided the groundwork analysis on the economic, technical, environmental features and social considerations of both BRT and LRT systems. In addition to the literature, data from jurisdictions who have implemented BRT and LRT systems was utilized, to illustrate the measurement criteria and served to provide high level jurisdictional information.

The sources of literature included the Summons @ UVic Libraries, Google Search, and the reference list of relevant articles and journals. Information reviewed was synthesized and grouped into relevant themes, corresponding to the MCDM/A transit project analysis measurement criteria.

Interviews

Primary data used in this research was derived from one-on-one interviews conducted with 10 individuals from the Regional Transportation Agency in Ontario. Interview participants were subject matter experts in Transit Planning, Urban Planning, Transit Economics and Engineering. A series of 12 questions was asked to participants in the same order and can be found in Appendix A.

The primary goal of the key informant interviews was to supplement the literature review findings, with information and insight, from transit planning professionals in the Ontario public transportation industry.

The interview questions were designed to build on the four MCDM/A criteria for measuring and assessing transit projects and provided insight into:

- Economic indicators of BRT and LRT systems, which included cost benefits, operating costs, maintenance, asset life and potential transit oriented development;
- Technical aspects included speed, passenger carrying capacity, safety and environmental efficiency; and
- Social indicators included passenger preference of each transit mode.

Interview candidates were selected from Ontario's Regional Transportation Agency, as this agency is responsible for transit implementation across the GTHA. Subject matter experts in Transit Planning, Urban Planning, Engineering, and Transit Economics were recruited for this research.

Candidates were contacted through telephone calls, inviting them to participate in an in-person or over the telephone interview. Participants were walked through the letter of consent prior to the interview commencing, and provided the interview questions in advance of the meeting.

The research method used in this paper followed an inductive approach, as it was largely centered on developing an explanation and comparative analysis of BRT and LRT systems, instead of using a theory at the beginning of research to direct the data collection (Teppo, 2015, p. 3).

Thematic analysis was used to analyze the semi-structured interview questions. This analysis allowed for the data to be segmented, categorized and summarized in ways that captured important concepts within the data (Ayres, 2008, p. 3). Interview responses were transcribed into a Microsoft Word document during the interview process. Participants were given the opportunity to review their recorded responses, to ensure the responses were documented accurately. Changes and edits were made as requested and captured in the final response.

Responses were examined by each question and coded based on the four MCDM/A criteria for transit project analysis. Similar codes were grouped together and reviewed to find common themes that emerged from the data. Codes were combined, divided and renamed as needed, depending on how respondents answered the questions. This process was iterative and evolved during the data review stage as certain themes across the responses continued to emerge.

This method of analysis was appropriate given the need to search for patterns and themes within the data, which assisted in addressing the research question. Thematic analysis also allowed for the patterns of commonality to emerge across the interview data and accounted for the contextual aspects which account for the differences among the participants as the data was deconstructed (Ayres, 2008, p. 5).

Passenger Preference Survey

A passenger preference survey was developed to measure the transit rider's perspective of BRT and LRT systems. The survey was administered randomly to 121 public transit users at Toronto's Union Station. After addressing the letter of consent, the survey began with a photo of a LRT system and a BRT system. Participants were then asked a series of 12 questions, based on the two photos. Questions were designed to gauge the social preference of public transit users, with respect to the mode of transit preferred for use, reliability, speed, passenger accommodation, design features and station infrastructure. Appendix C includes the survey provided to participants which includes a series of demographic questions, as well a measurement of public transit usage, to allow for a better understanding of the sample population.

Analysis of the data was done using Microsoft Excel. Appendix B contains the tabulated data and descriptive statistics, which provide insight into the sample population.

Methodological Strengths and Limitations

A key strength of this report is that several different methods of research were utilized to develop a comprehensive and integrated analysis of both BRT and LRT systems. This integrated approach best addressed the research question, as it provided a broad view of both transit systems. The literature review provided the foundation of economic, technical, social, and environmental information related to both modes of transit. Supplemental cross-jurisdictional data on previously implemented transit systems was also provided. Key informant interviews served to provide information on implementation, infrastructure requirements, economics, and challenges associated with the BRT and LRT systems. Lastly, the passenger preference survey provided strategic insight into the perceptions of BRT and LRT systems from actual public transit users across the GTHA.

There were limitations associated with this research study. Firstly, a competitive analysis between driving and public transit was not conducted. Secondly, key informant interviews were only recruited from Ontario's Regional Transportation Agency. Other jurisdictions which have regional transportation agencies were not selected to participate, thus limiting the subject matter expertise to Ontario only. The GTHA comprises many cities, including Toronto; however the passenger preference survey was done at only one location in Toronto. Due to the timeframe to complete the project, it was not feasible to complete more interviews and surveys outside of the Ontario Regional Transportation Agency or at other areas within the GTHA. As such, the opinions of the transit planning experts at Ontario's Regional Transportation Agency may not be representative of the transportation planning industry as a whole. Lastly, the small sample size of transit passengers surveyed may not be entirely representative of the population in the GTHA.

The next section of the report outlines the theoretical framework, detailed findings from the literature review, key informant interviews, and passenger preference survey.

3.0 THEORETICAL FRAMEWORK

New Public Management

The theoretical framework used to develop the interview questions and inform the process, was based on the theory of New Public Management (NPM). Specifically, gaining the most value of tax-payer dollars and demonstrating a sound stewardship of resources. The Ontario government has committed to eliminate the current deficit by 2017-18 while continuing to make investments in priority areas, such as transit. With a focus on deficit elimination and fiscal sustainability, the Ontario government will be looking to achieve the most out of public sector resources. Large scale transit investment decisions will need to demonstrate financial efficiency and a means of realizing value-for-money.

In an effort to ensure fiscal sustainability, governments have placed a premium on leveraging value from tax-payer dollars. This transformation has crossed many policy arenas including health, education, and public transportation, falling under the rubric of NPM (Ferris & Graddy, 1998, p. 225). Fiscal decentralization represents a theme under NPM and involves governments improving service delivery by capitalizing on the knowledge of other areas of government and delegating service delivery (Ferris & Graddy, 1998, p. 232). This is the current model of operation within the Ontario government as it relies on their Regional Transportation Agency to implement approved transit projects. A certain degree of risk is present as the government depends on another area of expertise to implement stated public policy objectives. As a means of ensuring provincial transit policy objects are met, funding is provided to the agency in the form of subsidies and transfers.

As the Ontario government operates in a pluralistic democracy, various stakeholder groups have a vested interest in the outcome of public transit policies, some of whom directly impact the decision process at various stages (Ferris & Gaddy, 1998, p. 230). Budgetary constraints driven by current economic conditions, place pressure on the Ontario government to improve public transportation in sustainable manner.

Government budgets are fiscally constrained and under pressure from key sectors for additional funding. This is not only prevalent from the transportation sector, but also from other competing sectors such as education, health, and law. Therefore, is it important for the government to invest in public transit that will deliver tangible societal benefits in the most efficient and sustainable manner (Hensher & Mulley, 2015, p. 28).

Application of NPM to LRT and BRT Systems

The theoretical framework of NPM and achieving value-for-money has served as the basis of measurement and analysis of both LRT and BRT systems. Value-for-money is assessed through a lens of economic metrics, technical features, environmental efficiency, and social perception based on the MCDM/A method of transit project analysis as described Zak (2011). Zak (2011) notes public transit projects involve many complex operations with important impacts to various stakeholder groups, as such, transit projects should undergo a comprehensive analysis of economic, technical, environmental, and social considerations and (p. 2).

Economic considerations include the opportunity for land use development, the cost to operate and maintain the system once it is operational, and the capital cost required to construct the new transit system. Technical features included transit technology speed, passenger capacity, and safety. Environmental efficiency was assessed against both modes and lastly, the social perception of transit riders was measured to provide a sample view of the perception of actual public transit system users. In addition to pressure from competing sectors, governments are facing increased scrutiny over internal priorities. This assessment criterion provides measurable standards to find the optimized balance of priorities based on the rapid transit investment proposal under consideration.

The MCDM/A criteria is grounded on the principles and foundation of new public management as the government must deliver transit in the most efficient, effective manner, ensuring stewardship of resources and value for money.

4.0 LITERATURE REVIEW: A COMPARATIVE ASSESSMENT

This literature review aimed to provide an overview and foundation of knowledge required to develop a comparative assessment of both BRT and LRT systems. This section of research involved a comprehensive review of academic journals, research reports and other published material on both modes of transit technology. The literature review was guided by the theoretical framework and criteria of MCDM/A for analyzing transit projects. Similar information from the literature review was grouped together into the following categories:

- 1) The rise in popularity of BRT and LRT systems due to their respective economic advantages in the areas of operating costs, capital cost of implementation, and potential for transit oriented development;
- 2) Design specifications and technical features including passenger carrying capacity, speed and system safety; and
- 3) Social preference of each transit mode.

4.1 RISE IN POPULARITY AND THE ECONOMIC FACTORS OF LRT AND BRT SYSTEMS

This section of the literature review highlights the rise in popularity of BRT and LRT systems, coupled with the debate between technology choice and explores the economic advantages of both public transit methods.

Popularity and Transit Technology Debate

Literature on the construction of BRT and LRT systems arose from the need to increase investments in public transportation projects, as a means of improving mobility, reducing congestion, and responding to environmental concerns. Over the last few years, governments across the world have been building BRT and LRT systems to provide an effective and reliable high-speed transit service, as an alternative to heavy rail. Many developed and developing countries are finding ways of providing efficient and effective public transportation that does not come with the high price tag of heavy rail and delivers value for money (Hensher & Golob, 2008, p. 501).

Given the rise in popularity of both methods, the choice between BRT and LRT is a topic heavily contested, without an agreed conclusion. Black (1993) notes there has been a major debate in the transportation planning industry between those who want new rail based systems and those who favour all bus modes; however, LRT is still the most popular transit technology. Currie and Delbosc (2011) have found that BRT systems are being embraced world-wide as an increasingly popular public transit development option, as BRT systems are capable of providing rail like quality for a fraction of the cost.

Hensher (2007), a popular BRT advocate, indicates that after many years of trying to instill relevance into the debate of LRT and BRT, it is easy to conclude that investments in light rail transit are widely assumed to be the better choice amongst decision makers and the general population. In evaluating transit systems in North America, Hsu (2013) notes that Hartford, Connecticut, selected BRT technology to upgrade their mass transit system; however, many people argue that LRT would have been the smarter choice. There are discrepancies in LRT theory and perception. There is an extremely high cost associated with light rail technology and such transit technologies are limited in their ability to service more than a specific corridor, thus neglecting the needs of a system wide network (Hensher, 2007, p. 98).

Capital Infrastructure Investment

The argument over costs between LRT and BRT is driven by the notion that BRT systems cost significantly less to implement and can offer rail like features for a fraction of the price. All literature reviewed was in alignment with the concept that the capital cost is higher for LRT systems compared to BRT systems. The capital cost of LRT and BRT technology can vary significantly with construction complexity and right-of-way functionality. A difference is present when comparing capital costs of BRT and LRT systems, as the estimating methodology per the Federal Transit Administration (FTA) is different between both modes of transit. Per the FTA, capital components of LRT systems are classified into eight cost categories (i.e. guideways, yards & shops, systems, stations, right-of-ways, special conditions, vehicles, and soft costs), while the capital cost structure of BRT systems is different due to the technology used and is categorized into five cost categories (i.e. running ways, stops & stations, traffic signal priority, vehicles and soft cost) (Hsu, 2013, p. 21).

The capital cost per unit of distance of a LRT system is on average higher than BRT systems due to the rail infrastructure, electrification, signaling, and higher cost of the transit vehicles (Hsu, 2013, p. 19). The Canadian Urban Transit Association (2007) outlined that BRT systems cost less to build than light rail transit systems, as this type of transit technology does not require specialized overhead electrical, track, and storage infrastructure. An additional aspect which causes variability in the cost base is the extent of roadwork required for implementation and length of the route.

In a recent study, Hsu (2013) highlights there is a large degree of inconsistency in the capital costs of BRT and LRT systems in North America, the low end cost ranged from \$16.5 million per mile for the Orange Line in San Diego (California), and up to \$112 million per mile in Buffalo (New York). Conversely, BRT systems ranged from \$7.4 million per mile in Miami, Florida to \$25 million per mile in Pittsburgh (Pennsylvania) (Hsu, 2013, p. 25). BRT systems also have the capability of being incrementally developed, allowing the implementation of the system in different phases, which works to spread out the capital investment (Maseo-Gonzalez & Perez-

Ceron, 2014, p. 149). Lastly, an audit conducted by the USA General Accounting Office in 2001, on BRT and LRT systems in six US cities, found that the capital cost per mile for LRT compared to dedicated lane BRT systems was on average 260% more costly (Hensher, 2007, p. 100).

Operating and Maintenance Cost

While there is an apparent agreement over the notion of capital costs for LRT exceeding those of BRT systems, the operating costs are a point of debate in the literature. Capital costs of both transit modes only represent half of the equation, when attempting to make a decision regarding transit technology appropriateness. Operating and maintenance costs are incurred as a result of operating the transit system and are largely driven by the size of the fleet, frequency of service, and capacity of passengers. Hsu (2013) points out the components of BRT and LRT operating and maintenance costs are similar, which can be broken down into vehicle operations, administrative, vehicle maintenance and non-maintenance, with labour representing the largest component of costs.

Additionally, Hsu (2013) describes that vehicle maintenance relates to fuel and servicing, while vehicle operations relates to operator wages, administration, ticketing, and fare collection. Non-vehicle maintenance costs are associated with fixing tracks, signals, and stations. Operating and maintenance costs are typically represented by distance driven, in dollars per vehicle per kilometer. The view traditionally held is due to the differing technology used by both modes of transit, LRT technology costs less to operate and maintain because of the higher passenger capacity of light rail vehicles compared to buses (Hsu, 2013, p. 20). Typically, one light rail vehicle consisting of three, sixty feet long cars, can carry as many people as four and one-half regular buses. To illustrate this point, Mackechnie (2015) describes a light rail train with three cars, operating every 10 minutes, would need to be replaced by 27 regular buses to move the same amount of people.

BRT systems require additional vehicles to match the capacity of LRT systems. More vehicles require additional operators and maintenance technicians to deal with repairs, as BRT vehicles do not last as long as LRT vehicles (McGreal, 2014, para. 8). Black (1993) supports this claim, indicating the capacity of one LRT vehicle can replace several buses, thus producing significant labour savings.

Furthermore, proponents of LRT argue this mode of transit technology allows flexibility in assigning capacity by running single cars in off-peak hours and adding cars during peak period travel, yielding economies of scale in operating costs (Black, 1993, p. 153). In a parametric cost model developed to compare operating costs of LRT and BRT, Bruun (2005) found many situations where LRT dominated BRT, as cars could be added or removed from the trains to

address demand. With BRT systems, increasing capacity can only be achieved by adding separate vehicles to the routes.

Mackechnie (2015) notes the LRT capacity / cost efficiency argument only holds true when passenger demand is constant. In a study which compared route demand in American cities, most cities did not have the demand required to warrant LRT systems, yet governments were actively electing to replace existing services with LRT infrastructure. As the vehicles are larger, capacity on the route is increased, yet the demand does not warrant the service, contributing to higher operating and maintenance costs compared to moving people with BRT systems (Mackechnie, 2015, para. 10).

While it is unclear the methodology behind costing the various components of operating and maintenance costs, data revealed from the National Transit Database (NTD) on operating costs, illustrates that it is more expensive to operate a light rail vehicle, compared to a bus. NTD data from 2010 revealed that it cost on average \$124 - \$450 per hour to operate a LRT vehicle and \$85 - \$164 per hour to operate a BRT vehicle (Mackechnie, 2015, para. 10).

There are a few primary reasons why it would cost more to operate one light rail vehicle versus one bus. Maintenance costs for signals, track and switches are said to be higher for LRT vehicles and the cost of electricity is usually greater than the cost of fuel, used for the buses (Mackechnie, 2015, para. 12).

Lastly, the issue of increased LRT capacity driving lower operating costs, is challenged by a review of 44 BRT systems internationally, conducted by Hensher and Golob (2008). BRT systems such as the TransMilenio in Columbia show that if configured properly, can carry more passengers per hour than many light rail systems, and have a maximum ridership of 35,000 passengers per hour (Hensher & Golob, 2008, p. 502).

Transit Oriented Development

Another issue across the literature concerns the ability of rapid transit to attract economic benefits such as Transit Oriented Development (TOD) to the communities in which they operate. Proponents of LRT argue it brings considerable benefits with regard to urban growth, land use, and revitalization. Topalovic, Carter, Topalovic & Krantzberg (2012) indicate the impact LRT systems have on land use is not coincidental, bringing significant economic benefits, when planned in conjunction with land use strategies. It is said that LRT implementation can influence developments in housing, offices, services and retail, in addition to aiding in the gentrification of a declining downtown core (Topalovic et al., 2012, p. 5).

In a review of Portland (Oregon), Dallas (Texas), and Denver (Colorado), three urban cities with declining downtown cores (office vacancy rates rising and retail fading), Topalovic et al. (2012)

note that office vacancy rates declined to levels below suburban office parks, witnessing increased rent and the development of retail hubs post LRT construction. In addition to land development, LRT systems are reported to have a positive impact on land value. In a study of land values since LRT implementation, in San Jose (California), commercial properties in proximity to LRT stations were worth \$19/square foot more, than other properties across the city (Topalovic et al., 2012, p. 6). Lastly, the benefits of LRT systems extend beyond the development of housing, office buildings and commercial space, by generating property tax revenue for the city, with the transit-oriented development (Topalovic et al., 2012, p. 6).

Counter to the theory of LRT increasing land use and property values, Chen, Rufolo and Ducker (1998) suggested that the proximity to light rail has a negative impact on land values, due to the nuisance effects of construction on the area. Topalovic (2012) tested the hypothesis made by Chen, Rufolo and Ducker (1998) in Portland (Oregon) and San Francisco (California) and found land values increased at LRT station notes as early as one year pre LRT construction.

It is recognized across the literature (Hensher & Golob, 2008; Gonzalez & Perez-Ceron, 2013; Hsu, 2013 and Hensher, 2006) that the renewed interest in BRT systems to provide more sustainable public transit can provide transit oriented development similar to LRT systems. While the benefits of LRT systems have been studied across the literature, perceived doubt does remain about the ability of BRT to achieve the same patterns of urban growth, partially due to the lower densities typically served by BRT systems (Cervero & Dai, 2014). Furthermore, empirical evidence on the ability of BRT systems to spur economic benefits is lacking. In the evidence of economic growth realized in Ottawa (Ontario); Adelaide (South Australia) and Pittsburgh (Pennsylvania), Cervero and Dai (2014) pointed out the absence of recorded controls, limits the ability to associate the growth with the improved transit services.

In a review of what is called the gold standard of BRT systems, Bogota, Columbia's TransMilenio, there was failure to develop mixed use developments near stations, primarily due to the cost-minimization aspect of the BRT systems (Cervero & Dai, 2014, p. 135). Given the choice to implement BRT over LRT is driven by the decision to save money, Cervero and Dai (2014) note the soft costs for transit oriented development features, such as streetscapes and public space enhancements, tend to be far down the priority list causing BRT to be viewed through a single lens of mobility rather than city shaping. However, Guangzhou, China's BRT system integrated transit-oriented features throughout each corridor and what followed was commercial development and real estate, leading to a 30% price increase in real estate value, two years following the opening of their BRT system (Cervero & Dai, 2014, p 137).

It is recognized that BRT implementation can change the way rail-like infrastructure is built and this represents a significant opportunity for restructuring urban growth. For BRT systems to realize the same economic benefits as LRT, the transit investment must be accompanied with

specific tools, including zoning reform, tax development policies, and supportive infrastructure to accommodate new development (Cervero & Dai, 2014, p. 129).

4.2 TECHNICAL FEATURES SPEED, CAPACITY AND SAFETY

Multiple factors contribute to the speed of travel, in both BRT and LRT systems. As both systems have various configurations, the comparison between both methods is not straightforward. System speed is dependent on the configuration of the system, meaning whether or not the system has an entirely separated right-of-way, is grade separated, and has signal priority. Grade separation refers to a separate alignment of both the traffic lane and the rapid transit lane to avoid any disruption upon the two transit modes intersecting.

Speed

In a review of 11 cities with BRT systems, Hidalgo and Graftieaux (2008) found the average speed of BRT systems to range from 40 km/h in Miami (Florida) and Pittsburgh (Pennsylvania) to 60-80 km/h in Cambridge and Adelaide (Australia). The higher speeds are achieved when systems not only have separate rights-of-ways, but are also grade separated.

As with BRT, many of the same factors such as dedicated right-of-ways, grade separations and signal priority, impact the speed at which LRT vehicles can travel. LRT vehicles are said to accelerate faster and have a maximum operating speed of 65-100 km/h, with newer vehicles being able to exceed 100 km/h (Durham Region Transit, 2009, p. 31).

Speed is also impacted by the distance between stops. Longer distances between stops, as modeled in rapid transit, allow for higher speeds to be achieved by vehicles. Conversely, an increased number of station stops, negatively impacts the ability of BRT and LRT vehicles to reach high speeds. Maeso-Gonzalez and Perez-Ceron (2012) argue that BRT will always be slower than LRT, given the shorter distances between stops.

Capacity

Capacity of LRT and BRT transit technology is a topic largely debated across the literature. Capacity directly impacts operating cost. By increasing the seating and standing capacity, you are able to increase the revenue generated. This results in a reduction of the overall cost to run and maintain either a BRT or LRT system.

Many LRT advocates argue the capacity of LRT vehicles, as a single car or train, can carry more passengers than BRT. LRT technology is said to be an intermediate capacity mode that can move more passengers along a corridor than BRT, specifically up to 20,000 passengers in one direction, per hour (Black, 1993, p. 153). This claim is made against the notion that buses were only able to carry upwards of 5000-6000 passengers per hour, per direction (Hensher, 2007, p.

99). Counter arguments are made to this statement, claiming BRT systems can move just as many people along a given corridor if the system is designed properly. Hensher (2007) conducted a global study of BRT systems and found multiple cities where the BRT system was able to move more people per hour. In Sydney (Australia), the BRT system is capable of moving 7500 people per hour, while their LRT maximum is 4800 people per hour.

This concept is further strengthened by Hensher and Golob (2008) who conducted a review of 44 BRT systems internationally and found two best practice BRT systems in Bogota (Columbia) and Curitiba (Brazil), which have peak capacities of 35,000 and 20,000 passengers per hour respectively.

LRT vehicle size is approximately 70 feet in length and trains usually operate in two or three car sets, referred to as consists. It is estimated that each vehicle is able to accommodate approximately 250 people and provide direct seating for 25% of the passengers (Hensher, 2007, p. 99). The capacity argument is that 250 people appears to be a substantial number, given that traditional buses are only equipped to accommodate approximately 60 people.

However, BRT vehicles are not equivalent to traditional buses. They are designed to move people in a fashion similar to light rail, as they are larger. BRT vehicles can range in size and, similar to rail systems, their capacity depends on the frequency of service, speed, number of stops, and vehicle size. On high demand BRT corridors, high capacity articulated 60 feet buses can carry upwards of 100 passengers and 83 feet, double articulated buses, can carry 200 passengers to meet demand (Hensher, 2007, p. 100). Along with being able to operate on all types of roadways, BRT systems allow for the operation of bigger or smaller vehicles depending on service need, and can change the fleet as required, meeting passenger demand (Maeso-Gonzalez & Perez-Ceron, 2014, p. 150).

Safety

When it comes to the system safety of both LRT and BRT systems, design features such as dedicated lanes, right-of-ways and grade separations play an important role in ensuring system safety, with other users of the road and pedestrians.

In a review of rapid transit systems in North America and Latin America, it was found that the main safety risks on a transit corridor depend more on the design than the type of transit technology (BRT or LRT) used, or the region of the world where it is implemented (Duduta, Adiazola, Wass, Hidalgo & Lindau, n.d., p. 7). Furthermore, the review pointed out that the most common type of collision involving transit vehicles occurred with center lane configured rapid transit systems and vehicles making left turns (Duduta et al. n.d., p. 8).

The topic of traffic safety is a recent addition to the literature on BRT systems, as up until recently, it has been primarily focused on the operational performance and implementation (Duduta, Adriaola-Steill, Hidalgo, Lindau & Dos Santos, 2013, p. 3). Duduta et al. (2013) note the most frequent type of accident on BRT corridors involve pedestrians attempting to cross the street at midblock and being struck by the transit vehicle, causing the majority of fatalities associated with BRT systems. In a review of BRT systems in Latin America, this problem was found to be more serious in Brazil and Columbia, which have BRT systems operating in the middle of the street, at speeds up to 80km/h (Duduta et al. 2013, p. 3).

When implementing BRT systems, street infrastructure and design are equally as important as the new bus routes. In developed countries, median-running BRT systems have generally proven to have a positive impact on safety (Duduta et al., n.d., p. 8). In a recent study conducted by World Bank Group, counterflow bus lanes, such as those located in Mexico City (Mexico) and Porto Alegre (Brazil), were found to be significantly correlated with higher crash rates for both vehicles, and pedestrians and are deemed to be the most dangerous configuration (Duduta et al., n.d., p. 9). Curbside lanes are often used on narrower streets, where the existing street infrastructure does not support a center lane and are also less problematic than counterflow lanes (Duduta et al., n.d., p. 14).

Commonly cited issues with the center, curbside, and counterflow lanes according to the Federal Transit Administration (n.d.) include:

Center Lane Configuration

- Significant left turn vehicle conflict with buses traveling straight through the intersection. Left turn prohibition is strongly recommended;
- Vehicle door configuration required, depending on the passenger platforms;
- Passengers must cross multiple traffic lanes to reach the station stops. Proper signaled infrastructure is required to ensure safety; and
- Large street width required to accommodate center lanes without reducing the capacity for mixed vehicle traffic.

Curbside Lane Configuration

- Difficulty to keep curbside lanes uncongested with illegal parking and standing;
- Right turning vehicles must wait for pedestrians to cross, causing delays; and
- High density areas require proper passenger waiting areas, as without them, people tend to wait on the side of the road, increasing the likelihood of injuries.

Counterflow Lane Configuration

- Bus lanes configured to run in the opposite direction of traffic, on what would be one-way street;
- Can cause serious complications at intersections and signaling; and
- Confusion by all parties on the road resulting in vehicular and pedestrian collision.

Similar to BRT systems, there has not been a great deal of research done in the field of LRT safety. Most studies lack statistically significant defensible methods, due to the limited amount of collision data available and inventory data on safety features implemented at the vehicle and pedestrian level (Cleghorn, Clavelle, Boone, Masliah & Levinson, 2009, p. 53).

One extremely important difference between LRT and BRT systems, is that LRT systems run on a fixed set of rails. Unlike buses and other motor vehicles, LRT systems cannot swerve out of the way to potentially avoid a collision between a motor vehicle or a pedestrian. Cleghorn et al. (2009) indicate collisions between pedestrians and LRT vehicles are the least common type of LRT related collisions and account for approximately 10% of collisions and 50% of deaths. Similar to BRT systems, road vehicles accounted for the majority of collisions with LRT vehicles, but only a small portion of the fatalities (Cleghorn et al., 2009, p. 65).

Like BRT systems, alignment of the transit system can have an impact of safety. LRT alignment is typically categorized into three right-of-way types. Cleghorn et al. (2009) describes the alignments:

Exclusive Alignments

- Use full grade separations of both motor vehicle and pedestrian crossing facilities, eliminating at grade crossing and operating conflicts, maximizing safety.

Semi-Exclusive Alignments

- Keeps the LRT vehicles apart from road vehicles and pedestrians, except where road vehicles and pedestrians intersect at an at-grade crossing.

Non-Exclusive Alignments

- Allows for mixed flow operation with motor vehicles and pedestrians, resulting in higher levels of operating conflicts and lower speed operations.
- These type of alignments are most often found in urban downtown areas, where there is willingness to forgo operating speeds, in order to access high population density areas.

A common problem across the literature was the issue of left turning vehicles across both center lane BRT and LRT systems (Duduta et al., 2013; Cleghorn et al., 2009). Duduta et al.

(2013) note while left turns are generally a road safety risk, they become particularly dangerous on center lane rapid transit systems and account for the most common type of accident, as cars can be struck by the transit vehicle approaching from behind. Cleghorn et al. (2013) found that most jurisdictions with semi-exclusive and non-exclusive alignments use left turn prohibitions at busy intersections; however, drivers often violate the turn prohibition and it is difficult to enforce.

4.3 SOCIAL PREFERENCE

Although there is a renewed interest in BRT systems in developed and developing countries, a perception problem exists amongst people that buses, regardless of whether or not they are part of a BRT network, operate in a constrained, mixed traffic regime and trains have privileged, dedicated right-of-ways (Hensher & Golob, 2008, p. 501). Hensher & Culley (2014) depict that the physical image of public transportation systems, as perceived by users, has long been put forward as a powerful influence on the formation of individual preference.

Black (1993) claims the social stigma associated with buses has been ingrained into our mindset, as cities have long relied on buses to move people. Buses portray an image of being slow, dirty, and uncomfortable as they historically ran in mixed-traffic and provided low-quality service to people who did not have access to a private vehicle (Black, 1993, p. 152). LRT systems emerged as a new alternative to bus based public transit technology. These systems were touted as speedy, exciting, powerful, and a true representation of advanced technology, providing superior comfort, quality, and reliability (Black, 1993, p. 156). Simply put by Black (1993), trains are sexy and buses are not.

Much of the public debate between BRT and LRT systems is seen as being emotional, including the image of both systems (Hensher & Culley, 2014; Black 1993). Black (1993) notes that, undoubtedly, rail has been oversold, as most decision makers have a fascination with LRT technology. There exists an emotional attachment to LRT systems, which is not aligned with the widespread desire to construct cost effective, public transportation systems (Black, 1993, p. 158). Despite capital costs of LRT systems significantly outweighing those of BRT systems, rail based technology almost always achieves greater buy-in and support from policymakers and the general public (Hensher & Culley, 2014, p. 8).

A gap in the literature exists when looking at images associated with different modes of public transportation. Hensher & Culley (2014) note many early contributions in literature focused on the image of public transport, in relation to its competitor, the motor vehicle. The concept of image was determined to be the principle cause of why the car is favoured and public transit, as a mode of choice, is viewed as the less popular choice (Hensher & Culley, 2014, p. 8). Lastly, psychosocial aspects are said to directly influence the image of poor public transit. According to

(Hensher & Culley, 2014), people who choose to use their personal vehicle, compared to taking public transit, gain psychosocial benefits such as prestige, self-esteem, and mastery.

The concept of user familiarity has been cited as having an influence on the perception and image of public transit systems. People are familiar with LRT systems in developed countries, leading to a more positive image of the system (Hensher & Culley, 2014, p. 10).

According to Scherer (2010), it is widely recognized that both urban public transport systems, bus and light rail, are valued subconsciously in different ways despite offering the same service characteristics. The subconscious viewpoint can be associated with the speed of rail and perceived reliability, given it operates on its own right-of-way. Also contributing to the perception of LRT superiority, is that new spatial developments often take place in neighbourhoods where LRT and commuter rail projects are under construction (Scherer, 2010, p. 14).

In an attempt to explain what influences perception, the idea of salient factors is explored by Scherer (2010). Scherer (2010) indicates people have a limited capacity to process and store information, yet are extremely sensitive to salient factors when gathering information. It is the property of stimulus that attracts attention, to which a value is encoded. Transit specific salient factors include novelty (i.e. intelligent transportation systems, new vehicles), visual design (i.e. design of stops, branding), visual dominance (i.e. visibility of routes due or dedicated lanes, frequency of service) and media presence.

Scherer (2010) explains that different valuations of transit systems can be the consequence of these salient effects, contributing to the reason LRT systems gain more attention, as LRT systems often have a stronger visual dominance and media coverage during construction. The work of Hensher and Mulley (2014) further elaborates on the concept of salient features, claiming it is the salient features of bus based systems, which have contributed to the tainted reputation of BRT systems, through indirect association. The work of Scherer (2010) further supports the view of Black (1993) and Hensher (2007), that people naturally favour LRT systems over BRT due to their perceived image.

Hensher and Mulley (2014) undertook a correlation analysis between the preference of LRT or BRT and factors such as familiarity, age, income, and use of public transit to determine what (if any) factors influenced perception. Capital cities in Australia were selected for the study, some having large LRT systems and some cities being BRT based. Out of the 1370 randomly selected people, 73% preferred LRT systems for everyday use (Hensher & Mulley, 2014, p. 13).

An important correlation was found between the use of transit technology and preference, suggesting familiarity and visualization can strengthen the salient factors, which shape perception as highlighted by Scherer (2010). The results of the study suggest that experience

through using the transit system (LRT or BRT), has a statistically significant influence on the probability of preferring a specific mode (Hensher & Mulley, 2014, p. 15). An additional statistically significant correlation was found with income and preference, suggesting LRT is viewed to a greater extent as a premium or luxury mode of transportation. Hensher & Mulley (2014) note income was not given much attention in the literature of passenger preference, yet based on the results of their study, increased personal income is associated with an increased preference for LRT technology.

A takeaway of the study conducted by Hensher and Mulley (2014) is that the image associated with each transit mode must be taken into account when promoting modal options. Market segmentation may be useful when informing and promoting modal choice, as salient characteristics are correlated with demographic variables, such as age and income.

Lastly, Scherer (2010) underpins the notion that there is a natural preference for LRT systems, as they are said to increase ridership when compared to BRT systems. However, in a study of LRT systems in North America, France and the United Kingdom, forecasted versus actual ridership was not what was expected. Demand forecasts for new LRT systems were found to be overstated in the United Kingdom and North America, while forecasted ridership in France was understated (Scherer, 2010, p. 17).

5.0 SUMMARY OF FINDINGS

The following section will provide a summary of findings for the key informant interviews and passenger preference survey. The purpose of the key informant interviews was to discuss the parameters of MCDM/A analysis with respect to BRT and LRT systems with subject matter experts who work directly in urban transit planning and implementation. Specifically the goal was to identify the following:

- Economic considerations;
- Technical features;
- Environmental efficiency; and
- Social preference / uptake.

The interviews were conducted with 10 individuals from the Regional Transportation Agency in Ontario, and included Transit Planners, Urban Planners, Transit Economists, and Engineers. Themes that emerged from the interviews are outlined below and are broken out by the major categories listed above.

5.1 ECONOMIC CONSIDERATIONS

Cost Efficiency

All participants indicated that BRT systems are generally more cost effective to build and implement than LRT technology. This is largely due to the lower capital cost involved in the roadwork, dedicated right-of-ways, and overhead catenary required providing the LRT with electricity. Furthermore, BRT systems could be scaled to only include dedicated right-of-ways in higher density areas and have far more flexibility to integrate with existing infrastructure such as storage sheds. BRT systems are seen as less of a separate transit mode, as the technology is still a bus. If BRT vehicles are purchased, existing resources can be redeployed throughout the network. However, it was noted transit is often built for the future, not for today.

Transit decisions should be based on a horizon year, plus an adjustment for population growth; meaning while it is more cost efficient to build BRT, it may not achieve the same ridership and urban integration down the road. Cost efficiency also needs to be measured on capacity and demand, not price. Demand is measured by the movement of persons per hour, per direction. BRT on average can move between 3000-5000 passengers per hour per direction. Above this capacity, the per unit cost increases and greater efficiency can be achieved with LRT systems. BRT systems often experience operational issues dealing with higher capacities in North America.

Operating, Maintenance and Asset Life

Participants pointed out that BRT systems are cheaper to operate up to a certain point. Capacity and system headway are determining factors which influence operating costs. Unanimously, participants indicated at passenger capacities above 5000-7500 passengers per hour, per direction, LRT becomes cheaper to operate on a per passenger basis. Rail based technology has the ability to move more people per hour. To move the same amount of people with a BRT system, additional buses would be required, which adds to the operating costs through staff and vehicles.

In North America, the majority of public transit service positions are unionized resulting in higher labour costs, which can lead to cost inefficiencies when running multiple buses to move the same amount of people as an LRT system. In addition, due to the larger capacity, LRT systems can run at lower frequencies, and operating cost efficiency can be achieved with running larger vehicles. Lastly, although electricity for LRTs is typically cheaper than diesel fuel, corridor infrastructure can drive up operating costs. For example, if the LRT or BRT systems run underground in tunnels, proper ventilation requirements must be complied with.

Some participants noted BRT systems have lower maintenance costs as there is less infrastructure to maintain; however, fleet vehicles wear down faster than LRT vehicles. Bus parts such as rubber tires, diesel engines and overall use of the pavement cause rattling of the bus, requiring increased maintenance. Participants also indicated parts are generally cheaper on buses, compared to LRT vehicles; however, they do not last as long. It was noted that LRT systems are not as prevalent in North America and thus is a more difficult to achieve economies of scales related to maintenance costs. Also, it was generally agreed that LRT systems have additional infrastructure compared to BRT systems such as overhead catenary, rails and signaling systems, which all require maintenance; however, LRT systems have a much longer asset lifespan.

Generally, all participants indicated LRT systems have a longer useful life. Participants indicated the parts used in rail infrastructure last longer. Steel wheels on a track for LRT vehicles can operate for approximately 10 years, whereas bus tires require replacement in 3-5 years. Also, the capacity is larger on LRT vehicles resulting in wider headways (i.e. not running the vehicles as frequently) causing less wear and tear. It was noted a LRT vehicle generally has a useful life of 30 years, whereas the useful life of a bus is only 10-15 years.

Given the longer useful life of the asset, the daily cost of LRT maintenance is lower than BRT, once the system is operational. Additionally, it was noted that the LRT infrastructure (i.e. rail tracks, catenary etc.) has a useful life of up to 50 years before requiring overall rehabilitation. One participant also noted that LRT vehicles require less immediate maintenance as the parts

last longer. Lastly, it was noted that should BRT be the choice mode of technology, and passenger demand exceeds the general limits of between 5000-7500 people per hour, maintenance costs will increase as more buses are being used to move people.

Participants highlight that BRT and LRT vehicles require different maintenance facilities. Maintenance facilities are required for overall repair and preventive maintenance of the rapid transit vehicles. BRT systems can use existing bus garages should a new facility not be built. A new LRT line almost always requires an accompanying maintenance facility or garage. This is because the system runs on a dedicated track, meaning it must be guided to a special maintenance facility designed specifically for the repair of LRT vehicles, which can often drive up operating and maintenance costs.

Interregional Connectivity

The majority of participants indicated the type of transit technology chosen for improving interregional connectivity is really dependent on the market and area being served. These participants felt the type of transit technology did not matter when aiming to improve interregional connectivity. What mattered was the mode of transit was built effectively to serve the population over the next 20 years. Participants noted station stops required proper placement, pedestrian wayfinding was built at stations, and the layout of the network was properly integrated within the city.

Some participants noted the geography and distance of the system was an important consideration. It was noted LRT was better at improving connectivity in highly dense urban areas due to the build form of this transit technology, while BRT was better at improving connectivity in larger geographically dispersed areas.

Participants noted that while LRT carries a perception that it is a superior transit technology, it has limitations with improving connectivity. The majority of participants highlight that LRT systems do not have any flexibility as they run on a fixed track. It is more difficult for a LRT system to serve suburban land use patterns effectively as they are guided on rail infrastructure.

The majority of participants highlighted the benefit of BRT systems at improving interregional connectivity as the system offers flexibility across the network. It was noted that in radial systems, such as the one in the GTHA, flexibility is important and can more efficiently serve demand. For example, many buses can run on the BRT network, providing express and localized service as vehicles have the ability to pass one another. LRT vehicles cannot maneuver around one another, thus service is more fixed. BRT systems are able to provide strong east-west connections, using existing highway infrastructure, such as high-occupancy vehicle lanes. Participants also noted that BRT systems are more adaptable at connecting to various rail and

car-pool stations due to their ability to use both the dedicated BRT lanes and local mixed traffic roads, serving more markets.

Land-use Planning and Transit Oriented Development

Many participants cited the issue of permanence when it comes to LRT systems and transit oriented development (TOD). Visual permanence is created due to the dedicated set of rail infrastructure LRT vehicles travel on, as well as the overhead catenary equipment to supply electricity. As such, the visible infrastructure, coupled with the higher price tag, cause LRT to be viewed as more of a permanent transit system, generating further TOD. Additionally, participants noted the visible heavy rail-like infrastructure is often better integrated into the city scape due to the larger cost of the transit system. As LRT systems are often better integrated into the urban realm, investors are more confident in the transit investment, spurring surrounding development. It was noted that BRT systems are viewed as less permanent and since the construction investment is typically less, efforts are not made to promote intensification and development in the surrounding area.

A large number of participants highlighted the conventional wisdom that LRT systems allow for more TOD as they require a larger investment and are viewed as more permanent. However, it was noted that should BRT be implemented to a gold or premium standard, it can have the same effect as LRT systems. The notion of it's not what you build, but how you build it, was mentioned by a number of participants, indicating that both systems have the capability to foster TOD depending on what goes into the system. If BRT systems are built to possess the same qualities as rail infrastructure, including larger stations, pedestrian friendly route stops, dedicated lane-ways, off-board fare payment, city integration and marketing, the opportunity is there to leverage TOD. To leverage TOD, both systems need to be designed in conjunction with regional land-use planning strategies and regional growth plans. Participants highlighted the recent success of the York Viva BRT system in Newmarket (Ontario), which has leveraged TOD given the sense of permanence created with the premium stations, and visual impact of the painted roadways.

Building on the concept above, participants noted TOD will not be generated solely with the construction of a rapid transit system.

Participants noted while this concept applies to both BRT and LRT transit technologies, it is more often applied to LRT systems. One participant referenced a particular LRT system built in Ontario which did not properly integrate land-use planning strategies or surrounding developments to properly serve the market. LRT systems need to be integrated with the origins and destinations of passengers, in order to foster TOD.

If stations are not properly integrated to allow for ease of access to shopping malls, colleges, and other popular destinations, governments often end up with transit adjacent development, instead of the intended TOD. Participants added if the transit system does not serve the market, people simply will not use the system and utilize a different mode, such as a personal vehicle, for accessing their destination point. Another participant highlighted numerous cases in the United States where LRT systems were built on old freight corridors, in areas without proper land-use planning and population density. It was noted these areas failed to meet any of the planned growth and economic development goals that are often touted with LRT systems.

5.2 TECHNICAL FEATURES

Speed

The majority of participants indicated system design features play a critical role in the movement of passengers and speed of travel on both BRT and LRT systems. Without design elements such as dedicated right-of-ways and signal priority at intersections, both systems will experience reliability and speed issues. As both systems can operate at generally the same speeds, participants noted design largely dictates travel time. However, one participant noted since LRT systems are electric, they are able to generally accelerate faster and stop quicker, thus can move between station stops more easily. It was noted by one participant that the internal configuration of LRT vehicles is designed differently than buses, allowing for better flow of movement from people inside. This is able to reduce dwell time at stations, increasing speed between station stops and overall travel time.

Lastly, regarding speed of travel, participants cited that BRT holds an advantage when there is a mechanical failure or accident. Since LRT systems run on dedicated track, if a vehicle breaks down or there is collision involving the vehicle, service is halted. LRT vehicles do not have the capability to pass a broken vehicle or move around an obstacle. Buses, like regular vehicles are able to move freely as they are not guided by rails. This allows BRT systems to continue operations and maintain vehicle speed.

Passenger Carrying Capacity

Participants all acknowledged LRT vehicles can carry more passengers because of the larger vehicle size. It was noted there is a difference between the ability to move a set number of people per hour and carrying capacity on a single vehicle. BRT systems can move the same amount of people as LRT systems; however, there needs to be an increased frequency of vehicles running throughout the hour. LRT systems can operate at larger headways, meaning they can run vehicles further apart from one another, whereas BRT systems need to run vehicles closer together to move the same amount of people per hour. One participant noted that the problem with running buses close together is the issue of logistical pinch points. This

happens when buses become clustered together, similar to a convoy and create a backlog. Furthermore, participants noted that while BRT systems can move as many people as LRT systems, more vehicles and staff are needed, which directly increases operating costs.

Illustratively, one participant indicated you often need double the amount of buses, compared to trains to move the same amount of people. A second participant indicated double articulated buses are available, which helps increase carrying capacity per hour; however, the technology is not available in North America due to size regulatory restriction. Additionally, it was noted that BRT systems which do move as many people as rail, often have two dedicated lanes running buses in each direction. Unless the roadway and BRT system are an entirely new build, this largely is not possible in North America due to the width of roadways and the need to preserve vehicular traffic lanes.

System Safety

Participants highlighted system safety is largely influenced by the overall design of the transit system and level of signal priority the vehicles have. Safety is dramatically increased with the level of dedicated right-of-ways, as well as left turn prohibitions at intersections. Additional design features which influence safety include the level of bike lane integration, pedestrian access to stations, signalization at stations, and lane configuration such as center-lane or counter-flow on roadways. Participants noted a system is not made safe by solely focusing on the vehicle choice.

For a system to be safe, it must be designed to find the optimal balance between efficiency and transit vehicle, pedestrian, cyclist, and motor vehicle safety. Additionally, participants noted system safety can be hindered due to available ground conditions and space. Vehicles parked on the road, delivery trucks, idling vehicles, and the level of integration with mixed traffic are all factors which can impact safety and increase the potential for infractions. Overall, participants indicated the level of safety comes down to how integrated the transit system is in mixed traffic.

Participants indicated LRT systems were generally safer as a whole compared to BRT systems for several reasons. LRT systems typically operate with a larger amount of dedicated right-of-ways, minimizing the impact of integration with mixed traffic. As LRT vehicles are guided by a track, they rely less on a driver than other modes of transit. Increased automation of the vehicle also increases safety as there is less of a reliance on human control.

LRT systems rely on computers and signaling for operation. BRT systems rely solely on a driver, which increases the risk of human error and accidents. Additionally, rail is more heavily regulated than buses, requiring more stringent safety features to reduce accidents. Such features include rail gates and crossing arms, whereas buses follow the rules of the road, like

regular vehicles. Lastly, it was noted that buses do have the ability to swerve and avoid a potential collision, unlike LRT vehicles; however, generally were deemed to be less safe.

Environmental Efficiency

Participants noted environmental efficiency isn't about the type of vehicle chosen or technology mode. Environmental efficiency comes from getting people out of their personal vehicles and into public transit. The maximum benefit of a system can be measured by this set of parameters, as it is personal vehicle traffic which largely contributes to the level of greenhouse gas emissions in the air. Participants noted environmental efficiency relates to mode shift, where people change their way of accessing a commuter rail service, from driving to taking public transit as a result of a new LRT or BRT system.

When strictly looking at BRT vehicles compared to LRT, participants indicated LRT vehicles are more environmentally friendly as they are powered by electricity. Although diesel engines have come a long way in producing cleaner emissions, they still output greenhouse gases. Participants noted BRT vehicles are available in electric models; however, they are not good performers on longer distance routes due to the charging requirements which can impact the travel time of passengers. Participants noted electric BRT systems are good in urban environments, where there are lower speed routes and shorter distances as the vehicles have a difficult time reaching high speeds and accelerating on highways.

Participants noted most people assume LRT is the cleaner choice because the transit technology is electric; however, the source of the electricity must also be taken into consideration. If the electricity is being derived from a coal plant, the overall environmental impact is worse, compared to a diesel bus engine. Participants also noted the decommissioning costs of the vehicle must be taken into account when assessing environmental efficiency as certain parts, such as batteries, can be toxic on the environment. Lastly, participants noted environmental efficiency also relates to the number of people you can move per hour. Since LRT systems have a larger carrying capacity, they are deemed to be more environmentally efficient.

5.3 SOCIAL PREFERENCE AND UPTAKE

All participants highlighted LRT is far more favourable with transit users due to the stronger social preference LRT systems have over buses and BRT systems. Train infrastructure is viewed as a more modern means of travel as the technology used is further advanced compared to buses. Such technology features include intelligent transportation systems, on-board wayfinding, and payment mechanisms. Participants noted transit users also generally prefer the ride of rail based systems compared to the buses. The general consensus among participants for why people generally preferred rail to bus was because trains provide for a smoother ride in

the vehicle as it is carried by steel wheels on a track. Also, the electric engines make for a quieter commute and the inside of the vehicle is designed to accommodate more standing passengers, compared to buses. Buses travel on pavement which is not always smooth and the engine causes noise and vehicle vibrations, making it difficult to stand.

Participants highlighted there is a negative social and socioeconomic stigma associated with buses. People often think of buses as having odor issues, being overcrowded and poorly ventilated. In addition, the interviewees noted there is also a negative service perception with buses. Buses are often deemed to be slow, unreliable and have confusing service / route networks. Since LRT systems are guided on a track, people know exactly where they are going and do not have to worry about route variations. BRT systems are designed to overcome these issues, although they are still less socially acceptable, as people assume it offers a lower service standard due to its lack of perceived permanence, station infrastructure and vehicle technology.

Participants noted North America has a culture of not liking buses as they are seen as taking up capacity on roadways for mixed vehicle traffic. LRT systems are dominant in Europe due to the strong urban density and this has translated into a perception of them being better in North America. One participant noted European design is considered appealing and more elite, causing LRT systems to be viewed as fancy and more prestigious in North America. Participants noted a higher social perception translates into a willingness to pay more for the service, which can strengthen the case for LRT systems.

LRT systems are perceived to offer higher service as they are modern, and more money goes into planning as the system costs more than BRT systems. Positive perception is tied to the level of investment. Since rail costs more to build, it is assumed a minimum level of guaranteed service and value will follow. Also, since more money is spent on planning, LRT systems are typically better integrated into the urban form, promoting more design excellence.

Lastly, given the strong socially favourable perception of LRT systems, the political will for LRT systems is much higher compared to BRT. Participants noted Canada has a connection to rail based technology as it makes for a better news story, while BRT is seen as second best. While it is seen to be an uphill battle, participants highlighted that proper education and marketing can shift perception and user awareness. People need to see the benefits regarding service, stations, identity and ease of use, to draw a connection to the service.

Ridership Uptake

Participants noted factors to ensure ridership and system uptake were not exclusive to each transit system, rather similar concepts applied to both BRT and LRT systems. Participants noted sophisticated urban planning was a very large factor in ensuring ridership uptake. Proper

planning is critical to ensuring the system has a good alignment, meaning stops are in the right place, reducing journey times and maximizing operating speed. Planning also enhances reliability by integrating signal priority and lane dedication into the transit corridor. Knowledge of the market allows for system alignment planning and can ensure the transit system is designed to adequately serve the market and capture the ridership base.

Urban design and planning are also important features which contribute to the success of either transit system. These features include making it easy for people to access the station, way-finding once people are inside the station, multiple-door boarding on vehicles to increase boarding and de-boarding and off-board fare collection. In addition, improving station design is important to enhance the waiting experience for users. Branding of the new LRT or BRT line will play a critical role in generating a strong ridership base. One participant noted BRT systems need to ensure they look and feel like a LRT line, for success they cannot look and feel like a regular bus. Lastly, participants noted passenger amenities, such as Wi-Fi, adequate seating and cleanliness should also be factored into planning and design work.

Participants highlighted providing information to the public pre construction and once the system is operational is another factor which drives ridership and system uptake. Pre-construction includes providing information and educating the public about what is happening, what services will be offered and what this means for future passengers. Participants noted it is important to market the service offering and not necessarily the type of technology being used. Once the transit system is operational, information can be provided through intelligent transportation systems, which provide real-time trip information to users.

Additional Considerations for BRT or LRT Implementation

Participants highlighted a clear answer does not exist when looking to decipher whether BRT or LRT technology is more appropriate to implement. Participants indicated the existing urban form plays a role in determining when a particular mode of transit should be considered. LRT systems need distinct room on the road, where as BRT vehicles can more easily use existing infrastructure. Often, when implementing LRT systems, sidewalks must be removed and considerations are required for catenary equipment. One participant noted the physical operating space can impact construction costs, depending on the type of transit vehicle chosen. BRT systems require additional ventilation, compared to LRT systems, if a portion of the route travels underground through a tunnel.

Urban form also relates to the type of service being proposed in the geographical realm. In the suburbs, a LRT is not the more appropriate choice because of the distance required between stops and route configuration. In an urban environment, population density is higher, and routes are typically configured in a straight line, from point A to B, making LRT more appropriate. BRT offers greater flexibility to cover a wider geography and thus improve inter-

connectivity. If stops are spread out and the route has mixed stopping patterns, BRT is better suited as operators can run express and regular service. In urban, densely populated areas, LRT is a better fit as the vehicles are larger, meaning they can operate at wider intervals, distances between stops is often shorter and the area is walkable.

Participants noted ridership projections and the planned level of service must be considered when determining technology appropriateness. The choice of technology must be able to accommodate peak ridership, without vehicles becoming congested on the road or people being crammed inside a vehicle. If the projected ridership exceeds between 5000-7500 passengers per hour, per direction, BRT systems do not have the capacity to efficiently move people beyond that point. One participant noted in North America, a bus can carry approximately 60 people, an articulated bus can carry 90-100 and a LRT vehicle can carry 150 people per hour.

Cost and levels of government funding can also play a role in determining which technology to implement. Participants indicated BRT offers more flexibility and can improve inter-connectivity given it can be built with less money. LRT systems are typically very expensive to build and governments are faced with financial constraints given the economic environment and desire to control government spending. One participant indicated governments have the choice of building one LRT system, or up to four BRT systems, with an investment of up to \$1.5 billion.

Political will was also highlighted as champion for technology appropriateness. Participants noted politicians view LRT systems as a means of securing government investment and growing their city despite the higher cost. Participants noted LRT systems make for a good political story given the larger investment and construction required. One participant noted LRT systems allow for the political message of permanence and a strengthened city image. Due to the perception of increased reliability with LRT systems, participants noted politicians also cite LRT systems as being able to build a ridership base and spur economic development. Politically there is the perception that LRT systems can be used for revitalization; however, participants noted this isn't always the case. It was noted that difficulty arises when attempting to redeploy existing LRT vehicles across a transit network if ridership levels do not meet projections as specialized track and storage facilities are required. BRT systems offer far more flexibility within an existing network.

5.4 Passenger Preference Survey Results

The passenger preference survey was administered randomly to 121 individuals in an effort to gauge the social preference of BRT and LRT systems on a sample population. Participants were shown a picture of both transit technologies then asked to complete a survey. The survey questions can be found in Appendix C and the summarized results are provided below.

Demographic Data and Public Transit Usage

Demographic data was gathered from participants as a means of further understanding the social preference of various demographic segments of the market. Key demographics of the sample population are found below:

- Gender: 56% female and 44% male;
- Age: 10% between 15-24 years old, 70% between 25-39 years old and 20% were 40+;
- Residency: 44% reside in Toronto, 17% live in the GTHA and 39% indicated other; and
- Public Transit Usage: 21% use public transit 1-2 times per week, 8% use it 3-4 times per week, 22% use it between 5-10 times per week and 48% indicated not applicable.

General Preference for Use

Based on a photograph of a BRT and LRT, only 12% of the population surveyed indicated they would prefer to use a BRT for public transit use. 88% of the population sampled preferred to use LRT for their public transit needs.

Speed of Service

When the sample population was asked which mode they felt would provide faster service, only 8% of people selected BRT, while 92% of people felt the LRT would provide faster service.

Reliability

20% of participants felt that transit service reliability was better with BRT systems, while 80% of people surveyed felt reliability was greater with a LRT system.

Comfort of Ride

Participants were asked which transit technology they felt provided a smoother ride. Only 6% of the population sampled felt BRT provided a smoother commute. 94% of people felt LRT offered a smoother more comfortable ride.

Passenger Accommodations

The sample population felt LRT vehicles were cleaner and offered higher quality accommodations. Only 8% of population sampled chose BRT, while 92% preferred LRT.

System Design and Features

Participants believed that LRT systems provided superior vehicle and system design features including larger windows, improved accessibility, multiple door boarding and off-board fare

payment. Out of 121 people sampled, 17% selected BRT as having better design features, while 83% of people chose LRT.

Visual Identity

Participants were asked which system they believed resonated a stronger visual identity through branding, newer vehicles and better stations. Only 12% of the population sampled felt BRT systems had a stronger visual identity, compared to 88% of people who believe LRT portrays a stronger visual image.

Premium Service

Participants were asked which system they felt provided for a more higher-end, or premium public travel experience. Only 6% of the population sampled felt BRT provided a more luxury service, compared to 94% who believe LRT provides a better user experience.

6.0 DISCUSSION AND ANALYSIS

6.1 ECONOMIC CONSIDERATIONS

Many factors must be taken into consideration when examining the cost of both BRT and LRT systems. Simply looking at the initial capital cost of building the transit system does not provide a fulsome representation of the expenditures required for system operation, which if not outsourced, will be a cost subsidized by government. In addition, it is difficult to quantify and directly compare the cost structures for LRT and BRT systems as they are very different. Varying features of each system, such as level of dedicated right-of-way, corridor length, infrastructure, and vehicle type limit the ability for a true comparison between the two transit technologies.

Capital Infrastructure Investment

Generally speaking, BRT systems cost significantly less to build than LRT systems. The capital cost of construction is not as intensive, as the cost of roadwork required for right-of-way lane dedication is less. BRT systems also do not require the overhead catenary infrastructure required to provide electricity to vehicles, or special storage and maintenance facilities that LRT systems require. This is consistent with the findings in the literature which suggest on average, the capital cost per unit of distance is higher with LRT systems, compared to BRT, due to the rail infrastructure, electrification, signaling and higher vehicle cost (Hsu, 2013, p. 19) BRT systems allow for more cost scalability with respect to construction costs as the system itself allows for more flexibility. With a BRT system, only a portion of the corridor that is densely populated can have complete right-of-way lane dedication, while the remaining section runs in mixed traffic, or on an existing roadway. Maseo-Gonzalez & Perez-Ceron (2014) highlighted this point as the construction of BRT systems can be done in incremental stages, spreading out the capital cost. In addition, since BRT systems use regular rubber tire vehicles, existing infrastructure, such as storage, maintenance and re-fueling/charging facilities can be used within the overall transit network. This flexibility can significantly reduce the upfront capital construction costs required.

LRT systems are more fixed as they must operate entirely on dedicated tracks and do not have the option to leverage existing infrastructure, unless it is already present within the network. However, the cost of laying track and overhead catenary to allow the vehicle to reach the storage facility contributes to increased expenditures. Analysis must be done to determine whether leveraging existing infrastructure is financially beneficial.

Operating, Maintenance and Asset Life

While BRT systems are generally less expensive to build, the operating and maintenance costs vary between the two systems. Various system functions, such as capacity and headway impact operating costs. Conventional wisdom across several sources in the literature pointed out LRT

systems are cheaper to operate due to their larger vehicle carrying capacity (Black, 1993; Bruun, 2005; Hsu, 2013). However, based on further research from the literature review and key informant interviews, BRT systems typically cost less to operate up to a certain demand point. Demand is measured by the movement of people, per hour, per direction. Between 3000-5000 passengers per hour, per direction, operating a BRT system can be more efficient. Above 5000 passengers per hour, per direction, the per unit passenger cost increases and greater efficiency can be achieved with a LRT system. In North America, the technology for double articulated buses is not available. Therefore, the BRT system must rely on single articulated vehicles which can carry between 90-100 passengers. A single LRT vehicle can carry upwards of 150 people. If ridership is above 5000 passengers per hour, per direction, rail based technology is more appropriate as it has the ability to move more people per hour.

This claim is further strengthened by Mackechnie (2015) who stated LRT systems are only more cost efficient to operate if passenger demand is constant over the above threshold, if demand does not warrant the service, LRT systems are more expensive to operate. Due to the ability to carry more people using fewer vehicles, LRT systems become cheaper to operate on a per passenger basis over the 5000 passengers per hour, per direction threshold. To move the same amount of people, additional buses would be required, which contributes to increased operating costs through the additional vehicles and staffing required. Hensher (2007) supported this claim in his research, indicating that BRT systems are able to handle between 5000-6000 passengers per hour. Also, logistical issues such as bottlenecking become present when a transit system begins running more buses than the network can handle to meet demand. Lastly, since LRT vehicles can carry more people, they can operate at wider headways, meaning less frequent, yet still move the same amount of people, contributing to lower operating costs over the demand point, compared to BRT.

Maintenance costs are a second component which results in a direct fiscal impact to the operating expense budget, once the system is built. Repairs and maintenance on the corridor and transit vehicles are cheaper on buses as the parts are less expensive, compared to LRT vehicles. However, the useful life of an LRT vehicle is 30+ years, compared to a bus, which ranges between 10-12 years. A shorter useful life of an asset results in a larger depreciation expense on the financial statements, representing a direct fiscal impact to the government. A longer asset useful life allows for a lower depreciation expense, as the cost of the asset is spread out over a longer period. Furthermore, LRT vehicles have a higher residual value than buses, lowering the amortization expense, over the life of the vehicle. Although the LRT parts are more expensive to maintain, the vehicle network to support the transit system will last longer. As buses do not last as long, their parts require more frequent maintenance, compared to LRT vehicles.

Rubber tires run on pavement, causing wear and tear, while LRT wheels are steel and run on smooth track. Additionally, bus engines cause vibrations which loosen other parts of the vehicle, triggering added repairs and maintenance. As an example, bus tires are said to last between 3-5 years, while LRT wheels are said to last between 10-12 years. Lastly, since LRT systems can carry more people, they can operate less frequently, reducing the amount of wear and tear on the vehicles.

The same concepts apply to LRT infrastructure such as catenary systems and dedicated right-of-ways, as compared to BRT systems. LRT infrastructure is expected to last up to 50 years. BRT systems will also experience higher maintenance costs, if demand exceeds the system ridership limits. If ridership surpasses 5000 passengers per hour, more buses are being used to move people, resulting in increased maintenance requirements. Given these factors, once a LRT system is operational, the system operators typically realize lower maintenance cost per day, compared to BRT systems.

Transit Oriented Development and Interregional Connectivity

Additional economic considerations for examining transit proposals include the ability to provide interregional connectivity and leverage transit oriented development (TOD). Interregional connectivity is possible if the transit system, either BRT or LRT, adequately services the market today and the future planning horizon. Serving the market refers to bringing people where they want to go. Station stops need to be properly aligned, the system needs to be easy to access and allow for interchanges with other transit services.

Geography also factors into improving connectivity. LRT systems work well in dense urban environments due to their integration with the urban form and the need to go from east to west, or north to south. BRT systems work better to improve interregional connectivity in suburban areas as they can better serve the land-use patterns by not being fixed to a set of rail track. BRT systems offer flexibility throughout a network as they can manage demand and serve a radial network of routes and rail stations. The concept of BRT systems providing enhanced interregional connectivity is strengthened by Hensher (2007) who noted LRT systems are generally limited to specific corridors due to their permanent alignment on rail infrastructure.

To foster TOD, transit systems need to serve a market, as previously mentioned. If people do not use the system put in place, the economic development associated with the transit system often does not happen, regardless of the transit system implemented. Investors and property developers largely view LRT systems as more permanent than BRT systems due to the strong visual presence that LRT systems bring in the form of dedicated right-of-ways, overhead catenary, sleek stations, and fancy vehicles.

A sense of permanence works to create a level of confidence in the development community, spurring TOD. Also, since LRT systems often cost more to build, they are better integrated into the urban environment, which stimulates TOD. As BRT systems typically cost less to build, the systems are not viewed as permanently fixed to a region. Also, less money is spent on intensification efforts and development in surrounding areas, hindering TOD. Gold or premium standard BRT systems mimic rail like infrastructure through visible dedicated right-of-ways, sleek stations, distinguished vehicles, pedestrian spaces, and branding. This creates a sense of permanence for investors and in conjunction with other activities, can work to generate the intended economic development benefits of public transit.

6.2 TECHNICAL FEATURES

Carrying capacity and system speed are technical features which impact the ability of a transit system to move people between preferred locations at an efficient rate, minimizing travel time. For any transit system, either BRT or LRT, to move people in a timely manner the system must be designed to ensure efficiency. Without the use of dedicated right-of-ways and signal priority at intersections, both systems will experience reliability and speed issues. System design and the level of mixed traffic integration play a significant role in the determination of travel time.

Passenger Carrying Capacity and Speed

Since LRT vehicles are electric, accelerating and stopping is quicker and the internal configuration combined with multiple door boarding allows for shorter dwell time at stations, aiding to improve travel speed. This concept is highlighted in the literature of (Durham Region Transit, 2009; Maeso-Gonzalez & Perez-Ceron, 2012) which stated that LRT systems are able to accelerate faster and reach higher operating speeds due to the longer distance between stops. As noted above, the size of an LRT vehicle compared to a bus allows for more passengers per vehicle. With the proper configuration and design, BRT systems like the TransMilenio in Columbia, are capable of moving the same capacity as rail. However as the system configuration and vehicle technology is largely not possible in Canada, more vehicles are required, increasing operating and maintenance costs. Also, buses need to operate at shorter headways, to maintain the same level of passenger movement as LRT systems. This can cause logistical problems where bottlenecks occur. When running multiple buses at short distances between each other, pinch points can occur, if buses are traveling to a central station and the infrastructure doesn't provide the space to accommodate the influx of buses on the road.

Global BRT systems which can move more people than rail often have two right-of-way dedicated lanes, running in each direction. Such configurations require an entirely new build as roadways in North America typically are not wide enough to remove two traffic lanes in each direction and restrict them solely for BRT use. Doing so would remove a significant portion of

capacity for mixed vehicle traffic. Furthermore, double articulated bus technology is not available in North America; the only option is an articulated bus which can carry approximately 90-100 people. LRT vehicles have a capacity of 150 people. Consistent with the literature, Black (1993) noted that LRT systems are seen as an intermediary transit mode, next to heavy rail, that is able to handle up to 20,000 passengers per hour. In addition, Black (1993) claimed multiple buses can be replaced by single LRT vehicles due to their larger carrying capacity, achieving cost savings and economies of scale.

BRT systems do provide more flexibility as a whole, compared to LRT systems. This is particularly significant if there is an accident involving a LRT vehicle, or mechanical failure, as the BRT vehicle can move around a collision and keep travelling along the route. LRT vehicles become stuck as they operate on dedicated rails, hindering their ability of maneuvering around an obstacle, or detouring to keep the route on schedule.

Safety

Safety is not determined by transit technology choice, such as BRT or LRT, but by system engineering and design. Safety is largely increased in both BRT and LRT systems by the level of signal priority, left turn prohibition and amount of dedicated right-of-way lanes. The more a transit vehicle is integrated with mixed traffic, there is a greater chance of an infraction between a pedestrian or motor vehicle. Additionally, for BRT or LRT systems to be safe, things like pedestrian station access, bike lane integration, signalization at stations, and transit vehicle lane configuration must be considered. A safe transit system optimizes the balance between transit vehicle, pedestrian, cyclist, and motor vehicle safety. Duduta et al. (2013) conducted a review of LRT and BRT systems across North America and support this claim, noting it is the design of the transit system which dictates safety, not the transit technology used.

Apart from system design, LRT systems are viewed as safer due to their level of dedicated right-of-ways, minimizing the interaction with mixed traffic. LRT vehicles are guided by track and are more automated than other transit modes, meaning they are less reliant on human control and steering. Rail based technology is also more regulated, imposing additional safety measures which must be adhered to, such as crossing gates, compared to other transit modes. BRT systems have flexibility, meaning they have the ability to swerve and potentially avoid an infraction; however, their reliance on human control and increased interaction with mixed traffic allows for greater safety levels to be realized with LRT systems. The safety information revealed in the key informant interviews is not supported in the literature as Cleghorn et al. (2009) noted that most safety studies lack statistically significant defensible methods due to the limited amount of collision data available and list of implemented safety features to serve as a benchmark.

Environmental efficiency must be looked at in broader context, rather than at the mode of transit technology chosen. A transit system, either BRT or LRT, is environmentally efficient if the system is able foster a mode shift. Mode shift occurs when people change from one mode to another, in this case referring to people switching from a personal vehicle to public transit for accessing their destination or commuter rail service. As mentioned above, integrating bike lanes into the construction project allows people to access their destination using cycling and public transit, promoting mode shifting and increasing environmental efficiency.

Both BRT and LRT systems can use electric vehicles in their transit fleet. However, environmental efficiency is achieved by the amount of people moved per hour. A larger transit vehicle allows you to carry more passengers per hour and thus reduce the amount of emissions, per passenger mile. As LRT vehicles can carry more people, compared to BRT vehicles, they are thought to be cleaner and more environmentally efficient. Lastly, the source of energy is another important consideration. Coal, nuclear and hydro-electric are all types of industrial energies used to generate electricity. Each source of power produces varying degrees of greenhouse gases, with coal being the worst offender. It is important to understand the energy source providing each transit mode their power as the vehicle may be environmentally efficient, yet the power source supplying the vehicle is not.

6.3 SOCIAL PREFERENCE AND RIDERSHIP UPTAKE

LRT systems carry a stronger social preference amongst the general public compared to BRT systems. The natural perception is that LRT systems are superior to BRT for a variety of reasons. Rail based infrastructure is seen as more modern, providing features such as intelligent transportation systems, off-board fare payments and electronic trip-planning. As LRT system runs on rails and not pavement, it is perceived as offering a smoother, quieter, and faster ride.

Additionally, since LRT systems cost more to build, they are better integrated into the urban environment with fancy stations, sleek vehicles, and a sense of identity. This likely contributes to people placing a higher perceived value on this mode of transit technology, compared to BRT systems. Perceived value is also placed on this mode as it is seen as more of an elite mode of travel. Bus based systems still struggle to move away from the stigma that buses are geared toward a lower socioeconomic demographic.

BRT systems are designed to provide rail-like service; except, the negative social stigma associated with bus based public transit still remains prevalent. Although BRT systems run on dedicated right-of-ways, provide off-board fare payments, utilize more modern vehicles, and have larger stations throughout the network, BRT systems are viewed in the same category as regular public transit buses. Black (1993) noted that bus systems still struggle to move away from the image of only providing services to people who did not have access to a personal

vehicle. Public transit buses are seen as being overcrowded, confusing and slow. This is consistent with the literature from Black (1993) which highlighted that bus systems carry a stigma of being slow, dirty, uncomfortable and unreliable whereas rail systems are seen as a modern representation of advanced technology. This negative perception hinders the ability for BRT systems to gain momentum and shift the preference to this relatively new mode of transit technology.

The favourable preference of LRT systems, coupled with the heavier infrastructure investment lends well to political messaging from governments. There is a strong degree of political will for LRT projects given the positive social preference of rail based transit systems. Consistent with findings in the literature, LRT technology generally achieves a higher level of support and buy-in from the general public and government, despite costing more to build, given the stronger visual presence and sense of familiarity generated from the infrastructure (Hensher & Culley, 2014, p. 8). Heavy infrastructure such as LRT is seen as a way of securing government funding and growing a city. Despite the heavier capital infrastructure investment required, politicians benefit positively from making announcements regarding funding for the construction of a new LRT line, compared with BRT systems which are viewed as the second best option. Given the perception of permanence, politically LRT systems are also seen as a way to strengthen a city's image and spur economic development. However, as mentioned in the literature review and key informant interviews, economic development and TOD is not guaranteed to follow LRT construction.

Success factors which contribute to ridership uptake include sophisticated urban planning and the integration of urban design into the transit system. These factors are not exclusive to either LRT or BRT transit systems. Similar concepts must be applied to both systems to attract as many riders as possible. Planning work is important to ensure the system has a good alignment within the network and surrounding geographical area. Stations and stops need to be located in areas that adequately serve the market and allow people to shift from using their personal vehicle to public transit. Integrating signal priority and lane dedication also work to ensure operational reliability and increase travel speed, which are captive traits when forming a new ridership base.

Planning also helps ensure ease of station access and passenger experience. People need to be able to access the station easily; otherwise mode shift is far less likely to occur. Once people are in the station, it is important for them to have a good waiting experience. Design elements such as adequate weather protection, natural light, Wi-Fi and other amenities make this possible. This concept is aligned with the literature from Scherer (2010) who noted that the valuation of public transit systems is based on salient factors such as novelty features, visual design and visual dominance, which people are highly sensitive to.

Education, marketing and system branding help to drive awareness about the new public transit system. During the pre-construction phase, providing information to the public is important as it helps to secure support from the general public. It is also an opportunity to market the planned service, communicating the expected services and benefits, until the system is operational. Once the system is operational, real-time information such as vehicle arrival time can be provided to passengers.

6.4 PASSENGER PREFERENCE SURVEY RESULTS

While a small portion of the sample population felt BRT was superior, the majority of people chose LRT as the better transit option. The passenger preference results demonstrate a strong overall preference for LRT systems with 88% of people preferring to use LRT systems for everyday public transit use. Participants overwhelmingly felt LRT systems are faster than BRT systems, provide more reliable service, offer enhanced system features and hold a stronger visual identity.

Over 80% of the sample population surveyed felt LRT systems provide a public transit experience that is faster, more reliable and more comfortable. 83% felt LRT vehicles offered superior system design features, leading to a better overall ride and 92% of the population felt LRT systems offer a higher level of passenger accommodations, including cleanliness.

BRT systems generally have a poor perception amongst the general population. As mentioned above, people typically associated BRT systems with the traditional public transit bus which are branded with a poor public image. The survey results are consistent with these findings in the literature and key informant interviews as only 12% of the population preferred to use BRT systems when taking public transit. Key informant interviews revealed people associate BRT with standard buses which have a lower perceived service standard. The survey results are aligned with the information revealed in the key informant interviews, as 80% of survey participants felt LRT systems were more reliable and 92% believe LRT systems provide faster service compared to BRT. Additionally, key informant interviews revealed people feel LRT systems offer more of a premium service, driven from the European focused LRT culture. The passenger preference data supports this claim as 94% of the surveyed population considered LRT to be more a luxury service.

Upon further analysis of the sample population, more males preferred LRT systems, compared to females. Out of the males who participated in the survey, 91% preferred LRT systems, while only 9% preferred BRT. Females surveyed still preferred LRT over BRT, although the results were slightly less at 85%. Interestingly, out of the 44% of the population surveyed who live in Toronto, Ontario, only 6% preferred BRT, while 94% of participants preferred LRT. This data supports the literature from Scherer (2010) who indicated that visual dominance impacts the

perception and value of transit systems. As Toronto has LRT systems in the city, residents are familiar with the salient factors of this transit technology, lending to a more favourable preference. Similarly, out of the 17% of the population who resides in the GTHA, only 14% preferred BRT, while 62% chose LRT. When analyzing the remaining 47% of the population who indicated they live outside of Toronto and the GTHA, 9% of the participants chose BRT, while 91% chose LRT as their preferred method of public transit travel.

Preference for BRT and LRT was also analyzed in conjunction with the amount of public transit use reported on the passenger preference survey. 81% of participants who used public transit the most (between 5-10 times per week) preferred to use LRT technology, compared to 19%, who prefer to use BRT. Public transit use in the range of 3-4 times per week resulted in a similar preference level with 80% of people preferring to use LRT. Intriguingly, people who indicated they did not use public transit, suggesting they walk or use a personal vehicle for commuting, and those participants who indicated they only use public transit 1-2 per week, strongly preferred LRT technology with data showing a 76% and 70% preference for LRT respectively.

Age of participants was analyzed with passenger preference results for the choice of BRT or LRT technology. Participants in the age group ranging from 25-39, had the highest preference for BRT technology amongst the other age brackets of participants. 14% of the participants in this age bracket preferred BRT, while 86% still preferred LRT. The lowest preference for BRT technology was in the 40+ group, with only 4% of participants preferring BRT technology, compared to 96% who chose LRT. The youngest age group also largely preferred LRT, with only 8% selecting a preference for BRT.

The passenger preference survey results are strongly aligned with the information revealed in the key informant interviews, suggesting that people generally always prefer rail to bus based public technology. While there is the concept that people have a natural draw towards LRT or train based public transit, the results in this study do not necessarily support that conclusion. The majority of respondents who indicated they do not use public transit had a stronger preference for LRT technology; however it is important to note their decision to select LRT over BRT could have been previously influenced by past use or experience with either technology. Figure 2 below represents the general preference for BRT over LRT based on the sample population surveyed.

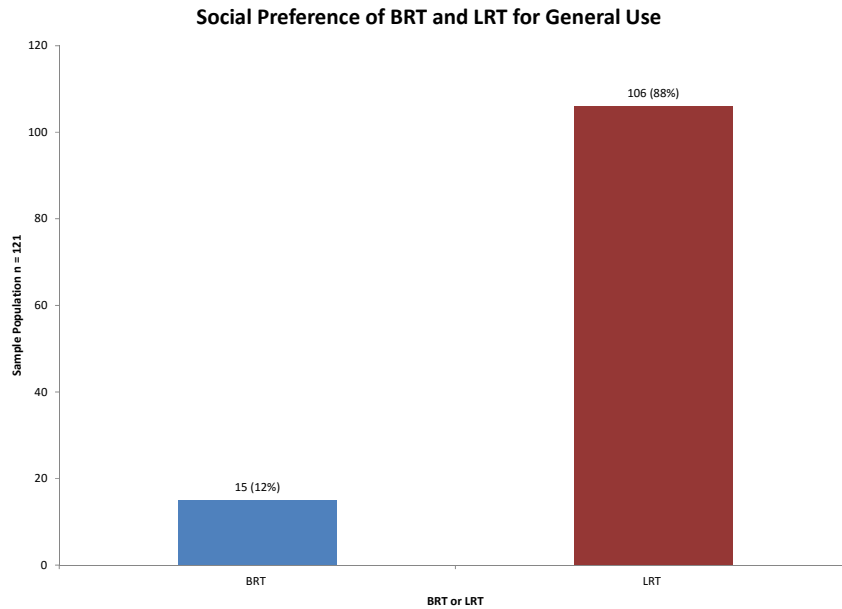


FIGURE 2. SOCIAL PREFERENCE OF BRT AND LRT SYSTEMS

The survey results also help to quantify that people place a higher perceived value on the service LRT provides, compared to BRT technology as it is deemed to be more modern, fast, cleaner and more reliable. Additionally, the survey results strengthen the argument that a negative social stigma remains present with respect to bus based public transit technology. It can be said that the oldest group of participants possesses the strongest negative stigma with BRT technology as this group had the lowest preferred choice for BRT use. This is aligned with the earlier generations of bus based public transit systems that fostered the poor reputation BRT systems continue to face today.

6.5 COMPARATIVE ANALYSIS SUMMARY

TABLE 1

COMPARATIVE ANALYSIS OF BRT AND LRT SYSTEMS

Consideration	BRT	LRT	Both	Comment
Capital Cost	√			Capital cost of building a BRT system is less than LRT. Vehicles and infrastructure requirements are less cost intensive.
Operating Cost			√	BRT systems are cheaper to operate under 5000 riders per hour. Over this capacity, LRT becomes more cost efficient.
Maintenance Cost			√	Demand impacts maintenance costs. If ridership levels are below the defined threshold, BRT systems are more cost effective. If ridership exceeds 5000 passengers per hour, LRT systems become more cost efficient to maintain. LRT systems are also more cost efficient to maintain at this threshold due to their longer asset useful life.
Asset Lifespan		√		LRT vehicles last for 30+ years, while a BRT vehicle will last between 10-12 years.
Interregional Connectivity	√			BRT systems are more flexible than LRT systems and thus can better improve connectivity.
Transit Oriented Development			√	Both BRT and LRT have the capability to foster transit oriented development with proper land-use planning strategies, creating a sense of permanence.
Passenger Carrying Capacity		√		LRT systems have the ability to carry more passengers per hour given the larger vehicle size. LRT vehicles can accommodate 150 people, while articulated buses can hold 90-100.
Speed			√	Speed depends on the amount of dedicated right-of-ways built into the network and signal priority. If these attributes are the same, both systems can function at relatively the same speed.
Safety		√		Safety is largely a function of design; however, LRT systems are safer due to the enhanced levels of automation and additional regulations in rail transportation.
Environmental Efficiency			√	Depending on the power source chosen to supply the rapid transit system with power, both systems have the ability to be environmentally efficient. Considerations include the nature of service being

				provided and the power source supplying the vehicle.
Social Preference		√		LRT is the preferred mode of public transportation technology with the general public. The perceived value of service and design is higher with LRT, compared to BRT.

The comparative assessment table aims to provide a holistic view of both transit technology modes and their ranking against the assessment criteria. As demonstrated in the table above, LRT systems are more appealing across the assessment criteria, compared to BRT technology. This is largely due to their longer useful asset life, lower maintenance costs, higher carrying capacity, system safety features, and stronger social perception.

A particular weight has not been applied to each assessment criteria, making it is difficult to draw the conclusion that LRT is superior based on this scoring methodology. The weighting and importance of the measurement criteria will vary as each transit project has a unique optimization of goals, based on the project. For example, BRT systems cost less to build and have the ability to generate TOD with proper land-use planning and integration. A fiscally constrained government may place a higher weighting on cost efficiency, causing the assessment to reflect a more favourable score of BRT systems. An optimized balance of each measurement criteria is typically achieved when selecting a transit technology mode, with the assessment criteria differing by project and intended outcome.

7.0 OPTIONS ANALYSIS

The government of Ontario has the option of two choice modes of rapid transit technology as a means of Moving Ontario Forward in the GTHA. The following section of the report outlines the key strengths and weaknesses of each proposed transit option.

7.1 IMPLEMENT ONLY BRT TECHNOLOGY TO MOVE ONTARIO FORWARD

TABLE 2

STRENGTHS AND WEAKNESSES OF IMPLEMENTING ONLY BRT TECHNOLOGY

Strengths	Weaknesses
<ul style="list-style-type: none"> • Cost is less than LRT • More cost efficient to operate and maintain under a defined ridership threshold of 5000 passengers per direction per hour • Enhanced network flexibility • BRT systems have the to generate TOD with proper planning and land-use strategies • Environmentally efficient if the appropriate vehicle type is chosen • Operationally efficient in less dense suburban areas 	<ul style="list-style-type: none"> • Perceived by the public and politically as the second best option • Strong negative social stigma associated with bus technology • Capacity issue could pose a challenge 20 years from the time of implementation • Assets do not last as long as rail-based technology

Relying solely on BRT technology as the choice rapid transit technology method would allow for more investments in public transit across the GTHA, given the lower capital cost required. Also, existing infrastructure could be re-purposed for use within the new system resulting in added cost savings. This could include converting existing roadways into dedicated BRT lanes and using existing bus maintenance facilities. Given the shorter useful life of BRT systems, system rehabilitation and vehicle upgrades would be required every 5-10 years.

BRT technology would work well in certain geographic areas across the GTHA which are less populated and walkable as this transit technology mode works well to serve suburban land use patterns effectively. BRT would be able to serve lower density areas, then utilize a dedicated right-of-way when required. This technology would allow for strong interregional connections across the various municipal transit service providers and larger commuter rail network. Given

the radial networks often found in suburban areas, LRT technology would not be as efficient or cost effective.

Additionally, BRT would serve the market well in areas which would not experience ridership demands upwards of 5000 passengers per hour. However, using only BRT technology would be limiting in densely populated, urban areas such as Toronto. The volume of people would pose capacity issues on key high traffic corridors, coupled with a more limited physical landscape. While this transit technology is more cost efficient, it may not be suitable for a longer-term planning horizon, or growth assumptions for a particular city.

Lastly, implementing only BRT would likely be met with resistance and opposition as a strong negative social stigma remains present with this transit technology. Additional communications and marketing related functions will be required to build BRT awareness and support.

7.2 IMPLEMENT ONLY LRT TECHNOLOGY TO MOVE ONTARIO FORWARD

TABLE 3

STRENGTHS AND WEAKNESSES OF IMPLEMENTING ONLY LRT TECHNOLOGY

Strengths	Weaknesses
<ul style="list-style-type: none"> • Strong degree of support for LRT technology • Transit technology can be well integrated into the city scape • Able to support increased capacity for densely populated areas • Increased safety due to higher levels of automation • Longer asset useful life • Sense of permanence lends well to TOD 	<ul style="list-style-type: none"> • Cost is higher than BRT • Lack of system flexibility and redeployment across the transit network • Achieving interregional connectivity is limited

Constructing only LRT systems across the GTHA would be the most cost intensive option and may not represent a consistent value for money. In urban areas where the city is densely populated, LRT is a better fit. However, it does not represent the better choice in suburban areas, where larger distances need to be serviced. In areas where ridership is lower, LRT systems do not represent the most efficient use of funding. However, if ridership in the planned corridor is estimated to exceed 5000 passengers per hour, LRT systems are more cost efficient

to operate and maintain. Additionally, the useful life of the asset is longer, meaning the government will not need to replace the infrastructure as quickly as BRT.

Due to the sense of permanence and perceived value LRT systems have, this option would bode well publicly and politically. People generally have a natural preference for rail-based transit, as such the choice to implement only LRT systems would be well received. Constructing a LRT system is seen as a way to strengthen the image of a city. Given the larger infrastructure investment, more money is spent on integrating the transit system into the urban environment. This integration helps to drive TOD and enhance a city image.

Lastly, only implementing LRT technology across the GTHA may not meet the intended objectives of the Moving Ontario Forward program to enhance interregional connectivity. Given LRTs are on a fixed track, their ability to serve mixed demand areas and longer distances is a challenge due to the high construction costs.

7.3 IMPLEMENT BOTH BRT AND LRT TECHNOLOGY

TABLE 4

STRENGTHS AND WEAKNESSES OF IMPLEMENTING BOTH BRT AND LRT TECHNOLOGY

Strengths	Weaknesses
<ul style="list-style-type: none"> • Better serve the market • Manage various market demand efficiently • More efficient use of resources • Allows for interregional connectivity • Strategic disbursement of transit investment based on need • Supports targeted infrastructure funding and efficient allocation of resources 	<ul style="list-style-type: none"> • May not satisfy public demand for wanting LRT over BRT

Constructing both BRT and LRT systems across the GTHA would allow for the most appropriate transit technology method to be chosen based on population density and design of the differing geographic areas. LRT systems need distinct physical space, while BRT systems can be integrated into existing infrastructure. Where ridership demonstrates it can warrant the construction and operating cost, LRT technology is a good candidate. Conversely, BRT technology is a good candidate when the route has many mixed stopping patterns and its population density is not as high. The hybrid approach also allows for a phased in operating

timeline as BRT is faster to build than LRT. Lastly, this approach allows for the strategic allocations of resources where they are required, building more costly LRT systems in highly populated urban areas and less expensive BRT systems lower density areas.

Constructing both BRT and LRT also allows for strategic decisions to be made regarding transit mode and the optimization of objectives. While an overall objective of the Moving Ontario Forward program is interregional connectivity, each corridor has specific objectives such as adding capacity or servicing a specific destination. BRT and LRT combined support interregional connectivity through their ability to efficiently serve different markets; however, each transit mode carries unique benefits that better lend itself to different environments. It has been demonstrated through the literature review and key informant interviews that both transit modes can largely provide the same level of technical functions such as speed, environmental efficiency, and their ability to generate TOD. Through proper planning and system alignment, the construction of BRT and LRT systems across the GTHA can support the development of a connected transit network while ensuring value for money and stewardship of resources.

8.0 RECOMMENDATION

The choice between rapid transit technologies remains a matter that is widely debated. While BRT technology is intended to mimic LRT, both BRT and LRT are distinguishably unique and have different service offerings that can present public transportation benefits to a region. Given the difference in these two transit modes, it is recommended that a combination of both BRT and LRT systems are constructed across the GTHA to fulfil the objective of improving interregional connectivity and demonstrating fiscal responsibility under the Moving Ontario Forward initiative.

There are 30 different municipalities which make up the GTHA and each has a diverse set of needs and population density. While Toronto, with a population of close to 3,000,000, is the largest city in the GTHA, there are smaller municipalities with populations ranging from 50,000-100,000 people. With such diversity across the regions, one mode of transit technology is not better suited over the other to meet the stated program objectives.

Infrastructure investments in rapid transit need to be targeted and carefully selected to ensure value for money. Targeted investments, in the form of BRT and LRT systems, allow for the maximization of transit projects by building bigger LRT systems where they are needed and smaller, less expensive BRT systems in markets with lower population densities. It would not be cost efficient to build an LRT system in an area that does not have the population density to support the infrastructure investment. Such an area could be better served through BRT technology which is less capital intensive and more cost efficient to operate and maintain at a lower ridership base.

Building both BRT and LRT across the GTHA, also supports the goal of interregional connectivity. LRT systems in large urban areas can connect to commuter rail lines and other heavier rail-based transit and BRT systems have the ability to provide strong suburban connections in a radial transit network. This is due to the operating flexibility BRT systems have over LRT, as they operate on roadways using either dedicated or mixed use lanes and are not fixed to a track.

From the analysis conducted on both BRT and LRT systems, the following additional short and long-term recommendations emerged to serve as a guide when TBS staff are reviewing transit investment proposals:

1. Transit Technology – Ridership

When building rapid transit projects, the choice between BRT and LRT transit technology should be driven by forecasted ridership over the long-term planning horizon of the transit project. Key informant interviews indicated this planning horizon is typically 20 years, plus a contingency

growth factor of 30%, as transit projects are forward looking. While many factors impact the decision whether to build a LRT or BRT system, ridership levels play a critical role in influencing the decision. Ridership indicates the level of system capacity required and the type of infrastructure needed to support it. Ridership levels are also indicative when one mode of transit technology becomes more appropriate over an identified alternative.

If projected ridership is estimated to exceed 5000 passengers per hour, per direction, it is recommended that LRT technology be considered, due to the fact it has the needed capacity to support this ridership level. Ridership above this level can support the construction and operating costs as efficiencies can be realized compared to BRT technology, making it more cost effective to operate. BRT systems can experience operational challenges above this ridership level as more buses are needed in service to move the same level of passengers.

Running additional buses at shorter headways also increases operating costs due to staffing and increased vehicle maintenance. In North America, most public transit positions are unionized, resulting in higher wages paid to staff. Since LRT vehicles are larger, they can operate at lower frequencies to move the same amount of people, resulting in cost efficiencies. Lastly, over the defined ridership threshold, LRT systems are more efficient to maintain as the vehicles have a longer useful life.

If projected ridership on the proposed corridor is less than 5000 passengers per hour, per direction, it is recommended that BRT technology be strongly considered as it is more cost efficient to build, operate, and maintain. When BRT is being considered, existing assets within the public transit network, such as maintenance garages, should be leveraged where possible for further expenditure synergies.

2. Geography

Correlated with ridership, the geographical area and urban landscape for the proposed transit project need to be considered when assessing the choice of mode. In suburban areas, BRT is more appropriate, as there is a larger geographical area to service with public transit, the landscape is not as walkable and the area is not as densely populated. Additionally, suburban areas typically have mixed stopping patterns that are not evenly spread out across the corridor, which can be easily served by a BRT system. A straight line LRT would be unable to accommodate the mixed stopping patterns. BRT systems have the ability to use regular roads, unlike LRT systems which are fixed to a dedicated track, allowing them to use flow through streets and provide express service, reducing the total journey time.

In densely populated urban environments, LRT is more appropriate, given the ridership demands and urban form. LRT systems integrate well into the urban realm, as areas are largely walkable and trip distances are short.

3. System Integration

Rapid transit proposals for either BRT or LRT projects need to adequately serve their intended market. This recommendation can be addressed in the short-term planning and design phase of the transit project. If the transit system is not properly integrated, people will simply not use the system. A public transit system which does not have a stable ridership base, will not realize any of the intended economic and environmental benefits which drive value for money. It is recommended that proposals brought forward for approval demonstrate knowledge of the ridership market with respect to origins and destinations to help ensure the market is being served. Stations and stops need to be aligned appropriately to reduce journey times, making public transit more competitive than the alternative of using a personal vehicle. Making public transit faster than driving fosters mode shifting, further strengthening the rationale for the investment and environmental efficiency.

4. Branding and Culture

LRT systems carry their own brand, and come with a high degree of perceived value. Although BRT systems are intended to provide rail-like service, the negative social stigma and perception of low service associated with buses remains prevalent. It is recommended that BRT proposals be accompanied with a marketing and engagement strategy, including public outreach at the regional and community level to educate the public. Education and awareness will help to break down the negative social stigma associated with bus based technology and will work to shift the social preference of LRT superiority. The following high level strategies are recommended for BRT systems:

- a) Market the service being offered, not the transit mode – public education in the short-term about what residents will get from the new service is a useful way to build awareness and support for the project;
- b) Showcase the permanency of BRT – fostering a greater sense of permanency with business developers in the short-term upon project approval will help leverage the economic benefits of TOD and work to change the social perception that BRT is less permanent than LRT; and
- c) Brand the BRT system – BRT systems need a unique identity to distinguish it from regular public transit buses. The same concept applies to the stations in the BRT network. It is important they do not resemble or feel like a regular station or bus. This will help to shift the social perception of low service, as people generally assume BRT systems operate like regular buses. Proper branding over the life of the BRT coupled with education presents the opportunity to change the perception of bus based public transit.

9.0 CONCLUDING REMARKS

This project aimed to provide a comparative assessment of the strengths and weaknesses associated with two choice modes of rapid transit, BRT and LRT. The goal of the research was to identify which mode of rapid transit should be used to meet the stated transportation objective of interregional connectivity and the need to maintain fiscal responsibility. To address this question, the project sought to identify the economic, technical, environmental, and social considerations associated with transit proposal analysis and decision making.

Main themes that arose from the research were:

- BRT requires less of a capital investment compared to LRT and is less expensive to operate and maintain, up to a ridership level of 5000 passengers per hour per direction. After this point, LRT becomes more cost efficient to operate and maintain due to the larger carrying capacity;
- LRT systems have a perceived sense of permanence due to the visible tracks and overhead catenary lending itself better to TOD;
- BRT efficiently supports interregional connectivity due to its flexibility over LRT;
- Speed, environmental efficiency, TOD and safety are relatively the same between both transit modes; and
- There is a major negative social stigma associated with bus based public transit and a very strong preference, both publicly and politically, for LRT due to its higher perceived value.

The literature of Hensher and Golob (2008) revealed many areas in Latin America which have experienced great success with BRT systems, having constructed systems that move as many people as heavy rail infrastructure in a given hour. However, key informant interviews revealed these systems often have two dedicated lanes operating buses in each direction, which is largely not feasible in North America due to the limited physical space on roadways and the need to preserve lanes for mixed traffic use. All research pointed to a general preference for rail based technology over bus. However, key informant interviews indicated that strategic marketing and awareness can work to shift the poor perception associated with bus based technology.

Options presented were based on themes uncovered in the research in conjunction with achieving the stated program goals of improving interregional connectivity while ensuring value for money. Three options were presented to meet the strategic goals of the Moving Ontario Forward initiative:

- 1) Build only BRT systems that are more cost efficient as an increased number could be built with the dedicated funding;
- 2) Build only LRT systems as this option is the most favourable option publically; and
- 3) Build both BRT and LRT systems to improve regional connectivity and ensure value for money.

The option recommended is for both BRT and LRT systems to be built across the GTHA. Value for money is achieved through an optimized balance of cost, economic considerations, passenger carrying capacity, safety, environmental efficiency, and social preference. Each proposed transit corridor under consideration for an investment has diverse demographics and requirements which cannot be served with only one mode of rapid transit technology.

It is hopeful this research serves to shed light on the benefits of both BRT and LRT technology and when each method should be considered as the appropriate transit technology choice. In an era of constrained government spending and the need to demonstrate fiscal responsibility, strategic decisions regarding the appropriate mode of transit, regardless of preference or political will, are required to ensure stewardship of resources and a long-term sustainable public transit system in the GTHA.

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APPENDIX A - INTERVIEW QUESTIONS

- 1) Based on your knowledge of transportation system implementation, which system is more cost efficient to implement and why?
- 2) Which system results in lower operating once the system is built? Are there system features which contribute to higher operating costs?
- 3) Which system results in lower maintenance costs once the system is built and operational? Are there system features which contribute to higher maintenance costs?
- 4) Which system has a longer useful life and why?
- 5) What are the strengths and weaknesses of improving interregional connectivity with BRT and LRT systems? Based on this information, which transit technology is better?
- 6) What are the strengths and weaknesses with BRT and LRT systems with respect to land-use planning and development efforts? Based on this information, which transit mode allows for a more transit oriented development and why?
- 7) Which transit mode can carry more passengers and operate with faster service and why?
- 8) Does one mode of transit technology offer superior safety features, or system safety as a whole?
- 9) Which transit mode is more environmentally friendly? Are there design aspects which can enhance the environmental efficiency of BRT and LRTs?
- 10) Based on your subject matter expertise in transit planning, what is the general social perception toward BRT and LRT systems and why?
- 11) When implementing BRT or LRT systems, what system features are critical to ensuring ridership uptake and system success?
- 12) When is it more appropriate to implement a LRT or BRT system?

APPENDIX B – PASSENGER PREFERENCE SURVEY RESULTS

Question	n	Exhibit A (BRT)	Exhibit B (LRT)
Which mode would you prefer to take for public transit use?	121	12%	88%
Which mode do you believe provides faster service?	121	88%	92%
Which mode do you believe provides more reliable service?	121	20%	80%
Which mode do you believe provides a smoother ride?	121	6%	94%
Which mode do you believe offers a higher quality of passenger accommodations, including seating / standing room and cleanliness?	121	8%	92%
Which mode do you believe offers superior vehicle and system design features (larger windows, improved accessibility, multiple door boarding and off-door fare payment)?	121	17%	83%
Which mode do you believe resonates a stronger visual identity (new vehicles, stations, and branding)?	121	12%	88%
Which mode do you believe offers a more luxury or premium service?	121	6%	94%

Demographic Data (n=121)											
Age			Gender		Residency			Public Transit Use			
15-24	25-39	40+	Male	Female	Toronto	GTHA	Other	1-2 per week	3-4 per week	5-10 per week	Not Applicable
10%	70%	20%	44%	56%	44%	17%	39%	21%	8%	22%	48%

APPENDIX C - PASSENGER PREFERENCE SURVEY



Exhibit A



Exhibit B

- 1) Which mode (A or B) would you prefer to take for public transit use:
A
B
- 2) Which mode do you believe provides faster service:
A
B
- 3) Which mode do you believe provides more reliable service:
A
B
- 4) Which mode do you believe provides a smoother ride:
A
B
- 5) Which mode do you believe offers a higher quality of passenger accommodations including seating/standing room and cleanliness:
A
B

6) Which mode do you believe offers superior vehicle and system design features (larger windows, improved accessibility, multiple door boarding and off-board fare payment):

A

B

7) Which mode do you believe resonates a stronger visual identity (new vehicles, stations and branding):

A

B

8) Which mode do you believe offers a more luxury or premium service:

A

B

Demographic Data

1) Age:

15-24

25-39

40+

2) Gender:

Male

Female

3) Do you live in:

Toronto

GTHA

Other

4) How often do you take public transit:

1-2/week

3-4/week

5-10/week

N/A