Urban Public Transportation Systems: Understanding the Impacts of Service Improvement Strategies on Service Reliability and Passenger's Perception

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ABSTRACT

Public transit systems offer essential services to the sustainability and livability of any city. One of the main challenges facing transit agencies is to offer a consistent and punctual transit service, or a reliable service, that is positively perceived by the public. During the past decade, transportation planning has shifted its focus from car mobility goals to embrace broader environmental and social goals, by providing and improving transport alternatives that offer access to destinations regardless of car ownership. This shift in paradigm, supported by enormous funding, has encouraged cities and transit agencies to incorporate various strategies to improve transit service operation with the goal of attracting new passengers and retaining existing ones. This has been done with no clear understanding of the strategies' actual effect on the quality of service or on people's perceptions.

With these issues in mind, my PhD research aims to develop ways of addressing the fundamental questions about how transit service improvement strategies can provide users with a better and reliable service that is positively perceived by the public. In light of these, this dissertation sets out to address several research questions:

- What are the areas of overlap and disconnect in understanding between the transit agencies and passengers perspectives regarding service reliability and the impacts of service improvement strategies?
- What are the benefits of implementing more than one improvement strategy for transit agencies? What will the passengers' immediate response to those strategies be?
- What are the impacts of implementing various improvement strategies on bus transit service variation?
- How do passengers' responses to those strategies change over time in terms of their estimation of their time savings?
- How can these findings be used to improve public transport planning and decision-making in the future?

These questions are addressed through four studies using mixed-methods of research design and multi-stage approach. The mixed-methods design includes qualitative analysis and several forms of quantitative research. The multi-stage approach is based on the idea of each stage (or chapter) building on the previous one.

A literature review that simultaneously addresses passengers' and transit agencies' perspectives on service reliability and the impacts of improvement strategies in an integrated manner is presented. In this study, first I use a systemic review method to identify and assess the international literature that covers the passengers' perspective of transit service reliability and their response to service adjustments made by different agencies. Second, I analyze transit agencies' plans and reports for fifteen transit agencies from North America regarding their reliability goals and the strategies employed in order to improve service reliability, while looking at the impacts of these strategies on service. Reviewing these two parts together provides a needed contribution to the literature from a practical viewpoint since it allows for the identification of gaps in the public transit planning and operations field in the area of reliability and the impacts of improvement strategies.

In response to the identified gaps in the literature, I have conducted several investigations using a unique case study from Montreal, Quebec, Canada, the Saint-Michel bus corridor. Saint-Michel is a heavily used bus corridor located to the east of Montreal’s central business district. In an attempt to improve transit service on the island, Société de transport de Montréal (STM), the transit provider on the island of Montréal, has implemented a series of strategies over a period of three years. These strategies include using smart card fare collection, introducing limited-stop bus service, operating reserved bus lanes, using articulated buses, and implementing transit signal priority (TSP).

An investigation of the collective impacts of strategies and the synergies between them on transit system running time and on users perception is done using stop-level observations (N= 2,270,000) collected from the STM’s automatic vehicle location (AVL) and automatic passenger count (APC) systems, as well as a field survey (N=354). The study indicates that strategies have unexpected impacts when they are implemented together. Users tend to overestimate the savings in their travel time associated with the utilization of the strategies, while there are almost no actual savings in their travel time in some cases. This shows positive attitudes towards the utilization of improvement strategies that are not only related to savings, but also to the implemented strategy.

A second investigation focuses on the impacts of various improvement strategies implemented by the STM and their synergies on the running time variation of the transit service. It indicates that the introduction of a smart card fare collection system increased bus running time and service variation compared to the prior situation, while other analyzed strategies have mixed effects on variation in comparison to the running time changes. These findings, which are based on a large set of AVL/APC data, are some of the most robust international results that can help transit planners and policy makers to better understand the effects of various strategies on different aspects of service variation. Nevertheless, a more detailed understanding of why users' overestimate their time savings and how these estimated perceptions can change over time is needed. This is an important policy-relevant issue, since agencies should understand the quantitative effects of their strategies not only on their performance, but also on users’ perceptions. Therefore, I have done a study that explores to what extent passengers overestimate their waiting and travel time savings, and how these estimated perceptions can change over time. The study analyses three surveys of bus user perceptions conducted over a period of three years (N=1037), while using the actual operational data and bus schedules to control for the actual changes in service. The results indicate that the implementation of various strategies has a short-term impact on users' overestimation of their waiting time benefits, while it has a long-term impact on their travel time overestimation. Furthermore, the study shows that some strategies more than others have positive impacts on users’ perceptions. These results elaborate on the current literature and current practice that traditionally ignores the range of temporal impacts of strategies and the differences between the effects of strategies on perception.

A concluding chapter ties the previous chapters together and presents policy and research implications. This dissertation highlights the importance of adopting mixed-method and multi-stage approaches in order to provide a comprehensive understanding of the benefits and impacts of improvement strategies on transit service reliability and users' perceptions. It contributes to knowledge in four key ways:

- It identifies the gaps and overlaps between passengers' and transit agencies' perspectives regarding transit service reliability and the impacts of service improvement strategies, as well as a set of indicators and approaches that capture users' reactions to transportation planning decisions.
- It develops methodologies to deepen understanding of the collective effect of strategies and the synergies between them on the performance of transit systems.
- It develops methodologies to understand the impact of various strategies and their synergies on transit system variation.
- It deepens understanding of how people respond to these strategies and to what extent they overestimate their time savings, and how these estimated savings can change over time.

By addressing these issues, this work explores an important gap in the current understanding of the relationship between passengers' perceptions and transit agencies' perspective and their implemented strategies.

RESUMÉ

Les systèmes de transport public sont essentiels à la durabilité et la qualité de vie de toute ville. Un des principaux défis des sociétés de transports en commun est d'offrir un service constant et ponctuel, c'est-à-dire un service fiable qui est bien perçu par le public. Au cours de la dernière décennie, la planification des transports a évolué en passant d'une pratique orientée sur des objectifs de mobilités pour dorénavant englober des objectifs environnementaux et sociaux plus larges, tout en améliorant les différentes alternatives de transports permettant d'accéder à des destinations indépendamment de la possession d'une automobile. Ce changement de paradigme, soutenu par un financement important, a poussé les villes et les sociétés de transports à adopter différentes stratégies pour améliorer le service de transport collectif affin de retenir les usagers actuels et d'en attirer des nouveaux. Ces changements sont survenus sans une bonne compréhension des effets de ces stratégies sur la qualité du service et/ou sur la perception des gens.

Considérant ces enjeux, mon travail de recherche de doctorat vise à développer différents moyens permettant de comprendre comment l'utilisation de stratégies d'amélioration de la qualité des services de transport en commun peut fournir un service plus fiable tout en ayant un effet positif sur la perception du public envers ce mode de transport. En lien, cette thèse vise à répondre à plusieurs questions de recherche :

- Quels sont les chevauchements et déconnexions entre la perspective des sociétés de transports et celle des passagers en ce qui concerne l'impact des stratégies d'amélioration du service et la fiabilité du service?
- Quels sont les avantages de mettre en oeuvre simultanément plus d'une stratégie pour les sociétés de transports ? Quelle sera la réponse immédiate des passagers?
- Quels sont les impacts de la mise en oeuvre des différentes stratégies sur la variation du service d'autobus?
- Comment les réactions des passagers évoluent-elles dans le temps en ce qui concerne leurs propres estimations du temps économisé?
- Comment les réponses à ces questions peuvent-elles être utilisées pour améliorer la planification des transports en commun et la prise de décision à l'avenir?

Ces questions sont abordées à travers quatre études d'approche méthodologies mixtes. Les approches méthodologiques mixtes incluent des analyses qualitatives et plusieurs formes de recherche quantitative. Élaborée en quatre étapes, cette thèse est basée sur le fait que chaque étape (ou chapitre) s'appuie et renchérit sur la précédente.

Dans un premier temps, une revue de littérature intégrée traite simultanément la perspective des usagers et de celle des sociétés de transports quant à l'amélioration des services de transport en commun et sa fiabilité. Dans cette première étude, j'utilise d'abord une méthode de revue systémique pour identifier et évaluer la littérature internationale concernant le point de vue des passagers sur la fiabilité des services de transport en commun et leurs réponses aux changements de service effectués par les sociétés de transport. Ensuite,

j’analyse les plans et rapports de quinze sociétés de transport en Nord-Américaines portant sur leurs objectifs en matière de fiabilité de leur service et les stratégies qu’ils utilisent pour rendre leur service plus fiable, tout en examinant les effets de ces stratégies sur les services. La recension de ces deux enjeux conjointement contribue à la littérature scientifique puisqu’elle offre un point de vue pratique sur le sujet tout en identifiant les lacunes de la planification et de l’opération des services de transport en commun en matière de fiabilité du service offert et d’étude d’impacts concernant les stratégies d’amélioration du service.

En réponse aux lacunes identifiées dans la littérature, j’ai réalisé plusieurs volet de la recherches en utilisant une étude de cas à Montréal (Qc, Canada) : le corridor d’autobus du boulevard Saint-Michel. Il s’agit d’un corridor très achalandé situé à l’est du centre-ville de Montréal. La Société de transport de Montréal (STM) a adopté une série de stratégies, sur une période de trois ans, dans le but d’améliorer le service de transport en commun sur l’île de Montréal. Parmi ces mesures, on compte l’usage de cartes à puces, l’introduction de lignes express, l’aménagement de voies réservées, l’usage d’autobus articulés, et l’installation des feux prioritaires pour bus.

Une première enquête mesurant les impacts des différentes stratégies d’amélioration du service (et des synergies existant entre elles) sur la qualité du service et les perceptions des usagers fut effectuée en récoltant les observations du système de localisation automatique des véhicules (AVL) et du système de comptage automatique des passagers (AVC) (N= 2,270,000), en plus d'un sondage sur le terrain (N=354). L’étude indique que certaines stratégies ont des impacts inattendus lorsqu’elles sont mises en oeuvre simultanément. Les usagers tendent à surestimer les économies de temps de parcours associées à l’utilisation de ces stratégies, alors que dans certains cas, les économies de temps réelles sont pratiquement absentes. Ces résultats démontrent la présence d’une attitude positive envers les différentes stratégies d’amélioration de la qualité du service de transport en commun qui n’est pas seulement lié aux économies de temps réalisées par l’usager, mais aussi à la stratégie mise en ouvre.

Une deuxième enquête, qui porte sur les impacts de différentes stratégies d’amélioration des services de la STM et leurs synergies sur la variation du service de transport, montre que l’introduction des cartes à puce a fait augmenter le temps de parcours des autobus et leur variabilité, alors que d’autres stratégies ont des effets mixtes sur la variation en comparaison aux changements en temps de parcours. Ces résultats, basés sur un grand ensemble de données *AVL/APC*, sont parmi les résultats internationaux les plus solides pour aider les planificateurs de transports et les décideurs à mieux comprendre les effets des différentes stratégies d’amélioration sur la variation de service. Néanmoins, il est nécessaire de mieux comprendre les raisons pour lesquelles les usagers surestiment le temps de parcours économisé, et comment leurs estimations évoluent dans le temps et influencent leurs perceptions du service. Cette question est importante en terme de développement de politiques. En effet, les agences de transport ne devraient pas seulement savoir les effets quantitatifs reliés à la mise en oeuvre de leurs diverses stratégies d’amélioration. Pour avoir une idée globale de leurs performances, les agences devraient aussi être en mesure de connaitre les impacts de ces stratégies sur la perception des usagers.

Par conséquent, j'ai réalisé une troisième étude explorant pourquoi les usagers surestiment leurs économies en temps d'attente et de parcours et comment leurs perceptions de ces temps évoluent dans le temps. Cette étude analyse les données de trois sondages portant sur la perception des usagers des autobus de la STM réalisés sur une période de trois ans (N=1037) ainsi que les données opérationnelles et les horaires des autobus dans le but de contrôler la présence de réels changements dans le service. Les résultats montrent que l'application de différentes stratégies a un impact à court terme sur la surestimation du temps d'attente économisé, tout en ayant un impact à long terme sur la surestimation du temps de parcours économisé. De plus, l'étude montre que certaines stratégies ont plus d'impacts positifs sur les perceptions des usagers que d'autres. Ces résultats complètent la littérature actuelle et la pratique contemporaine sur le sujet qui, traditionnellement, ignore l'étendue des impacts temporels des différentes stratégies, ainsi que l'existence de leur différent niveau d'influence sur la perception des usagers.

Une conclusion lie ensemble les chapitres précédents et présente leurs conséquences en terme de politique publique et de recherche. Cette thèse met en évidence l'importance d'adopter des approches méthodologiques mixtes comprenant plusieurs étapes pour parvenir à une compréhension plus complète des avantages et impacts des stratégies d'amélioration sur la fiabilité du service de transport en commun et sur la perception des usagers. Cette thèse contribue à l'avancement de connaissance sur le sujet de quatre manières :

- Elle identifie les écarts et les chevauchements entre le point de vue des sociétés de transports et celle des passagers concernant la fiabilité du service et l'impact des stratégies d'amélioration du service tout en identifiant un ensemble d'indicateurs et d'approches permettant de saisir la réaction des usagers envers les décisions d'amélioration du système de transport en commun;
- Elle développe des méthodologies pour approfondir la compréhension des impacts des stratégies d'amélioration et de leur interaction sur la performance du système de transport en commun;
- Elle développe également des méthodologies pour approfondir la compréhension des impacts des stratégies d'amélioration et de leur interaction sur la variabilité du système de transport en commun; et
- Elle permet de mieux comprendre la réponse des usagers à la mise en oeuvre de ces stratégies, dans quelle mesure ils surestiment leurs économies de temps et comment la variation de leurs estimations dans le temps influence leur perception du service de transport en commun.

En répondant à ces questions, ce travail explore une lacune importante dans la compréhension actuelle de la relation entre les perceptions des usagers d'une part et la perspective des sociétés de transport en commun et les stratégies d'amélioration qu'ils utilisent d'autre part.

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AUTHOR CONTRIBUTIONS

This dissertation consists of four manuscripts that have been published in peer-reviewed academic journals. These manuscripts were completed with co-authors; details of author contribution are given below.

Chapter two “Bus transit service reliability and improvement strategies: Integrating the perspectives of passengers and transit agencies in North America” by Ehab Diab, Madhav Badami and Ahmed El-Geneidy. Ehab Diab was the primary author of the manuscript. He reviewed the literature and carried out the data analysis and writing. Prof. El-Geneidy and Prof. Badami critically revised the paper, provided comments and approved the final version.

Chapter three “Understanding the impacts of a combination of service improvement strategies on bus running time and passenger’s perception” by Ehab Diab and Ahmed El-Geneidy. Ehab Diab was the primary author of the manuscript. He performed all of the statistical analysis, interpretation of the results, and writing. Ahmed El-Geneidy contributed intellectually and provided comments and edits on the manuscript.

Chapter four “Variation in bus transit service: understanding the impacts of various improvement strategies on transit service reliability” by Ehab Diab and Ahmed El-Geneidy. Ehab Diab was the primary author of the manuscript. He performed all of the statistical analysis, interpretation of the results, and writing. Ahmed El-Geneidy contributed intellectually and provided comments and edits on the manuscript.

Chapter five “Transitory optimism: changes in passenger perception following bus service improvement over time” by Ehab Diab and Ahmed El-Geneidy. Ehab Diab was the primary author of the manuscript. He performed all of the statistical analysis, interpretation of the results, and writing. Ahmed El-Geneidy contributed intellectually and contributed to the writing and editing of the manuscript.

PUBLICATION DETAILS AND PERMISSIONS

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1 CHAPTER ONE: DISSERTATION INTRODUCTION AND OBJECTIVES

1.1 OVERVIEW OF INTRODUCTORY CHAPTER

This dissertation addresses the fundamental questions about how transit agencies, through employing various improvement strategies, can better provide reliable service which is perceived positively by users. The introductory chapter starts with a discussion of the role of public transportation and bus transit systems in the community. This is followed by a discussion of the definitions and issues related to service reliability. After introducing these broad topics, I will highlight the gaps in knowledge that this research aims to address, as well as the research goals and objectives. This is followed by a detailed description of the ensuing chapters.

1.2 URBAN PUBLIC TRANSPORTATION SYSTEMS

Transport within urbanized areas presents unique planning challenge that has a direct impact on residents' quality of life. Within this framework, urban public transportation planning has the potential to attain many important environmental and social goals which transcend the commute of people. Indeed, the provision of public transport is not an end in itself, but rather a catalyst for more equitable and sustainable communities. A comprehensive perspective of the contribution to quality of life that public transport can make examines these four aspects: society, culture, economy and environment. Society benefits from a public transport system that provides equitable access to opportunities, responds to differing demands and needs, and allows us to continue with our daily activities even during periods of uncertainty. Public transit also contributes to the creation of distinctive and vibrant places with a varied and human-scale design that minimizes intrusions from the network of roads and parking requirements that come with massive automobile usage. It also contributes to the economy by enabling mobility, making efficient use of energy and spatial resources, and reducing in-vehicle travel time by mitigating congestion. Finally, public transit contributes to the environment when it is safe and increases the non-recreational physical activity of residents. It should also play a significant role in diminishing the air emissions, as well as the energy and material consumption needed for people mobility.

The years following the Second World War saw considerable urban growth along with an increase in automobile ownership, which in turn increased the need for expanding transportation infrastructure to accommodate the growing number of people facing longer travel distances. Traditionally, cities have reacted to an increase in mobility requirements by expanding the transportation supply, mainly by building new highways and more roads to handle the burgeoning number of vehicles. After the1970s, energy crises, growing traffic congestion and pollution, among other concerns, have shifted transportation planning from a focus mainly on car mobility objectives, to a perspective that encompasses different and broader environmental and social goals, by providing an equitable mode of transport which offers access to disparate destinations regardless of car ownership (Jabareen, 2006; Lucas, Marsden, Brooks, & Kimble, 2007).

Planners argue that “we cannot build our way out of congestion” since simply supplying more routes for cars merely induces more demand and consequently fails to address the problematic level of traffic congestion (Block, 1980; Downs, 2004). This was emphasised by the Lewis–Mogridge Position (Mogridge, 1990) which posited that increasing road space is not an effective way of reducing traffic congestion, as latent or induced demand emerges to restore a similar level of congestion “within months if not weeks.” As a result, many cities are currently opting for providing and maintaining competitive and attractive alternatives, such as public transportation systems along with other active transportation forms (e.g. walking and cycling).

This paradigm shift has further encouraged cities and operators to incorporate various strategies, policies and options (e.g., reserved bus lanes, articulated buses, and transit signal priority (TSP)) in order to improve the transit service operation. This has been done with no clear or certain understanding of their actual effect on the quality of service provided or on people’s perception of it. This is amplified due to the great expectations for the role that transit systems should play in the community, due to the various funding plans offered by different governments and cities in order to improve the service, and due to the inadequate use of indicators or accepted ways of measuring progress. Consequently, while these strategies or options often underlie policy making, they may have contradictory effects on transportation planning outcomes. On the other hand, the benefits of these strategies can be measured easily using a few direct indicators, such as increased ridership, reduced congestion, improved air quality, or running time reductions. They have inestimable outcomes related to passengers' perception of change, since passengers who are witnessing the implementation of such measures and their effects may have a different view than the actual change. This link between passengers’ perception of change and agencies' improvement strategies can generate political capital, by leading to more accurate integration between policy making and users’ perception. Eventually this relationship is more important now than ever, since transportation planning is squarely introduced to address many important social goals beyond mobility-based concerns, and its implications are currently on top of the political agendas at the municipal and provincial levels, where at least to some extent there are diverging views among planners and policy makers.

1.3 BUS TRANSIT SERVICE PLANNING AND OPERATIONS

Improving public transportation systems is about more than just upgrading infrastructure, such as building new lanes and transit routes; it is also about operating those systems efficiently. Good transport planning and operations are required to delicately balance the trade-offs among the goals and constraints of transit agencies (supply side) and the competing values of passengers (demand side). Because terminology and concepts in the field of transportation often vary, special attention has been paid to precise definitions throughout the dissertation. *Reliability* is a key concept in the planning and operation of transportation services and is presented in different ways throughout the literature (discussed in the following section). *Transportation service* usually refers to transportation offered to passengers while *operation* has a wide range of definitions covering system management, scheduling and functioning, particularly from the agency point-of-view (Vuchic, 2005). In the transportation setting, *planning* is an area that involves the evaluation, assessment, design and location of transportation facilities (Rodrigue, Comtois, & Slack, 2009).

A sustained growth of the economy and the continued improvement in overall quality of life has led to an increase in the value of time, and accordingly, to the value of quality urban public transportation systems which are reliable (Tahmasseby, 2009). In recent decades, improving the reliability of public transport systems has been considered a necessity by public transport users, community members, decision makers, public transport operators and government agencies (H. Levinson, 2005). The effects of reliability on ridership have long been discussed in the literature (Bates, Polak, Jones, & Cook, 2001; Nam, Park, & Khamkongkhun, 2005; Noland & Polak, 2002; Vuchic, 2005). Researchers argue that public transport patronage grows as a result of service reliability improvements, whereas patronage can erode due to unreliable service. For example, Schramm, et al. (2010) indicate that "one of the most difficult aspects of attracting ridership on a bus system is the variability in travel time" (p.77). Growth in ridership raises operators' revenues but usually necessitates an increase in the degree and scope of required services. Levinson and Krizek (2008), among others, illustrated this relationship as a positive feedback loop. Further, reliability is important for operators because it can easily improve their internal efficiency. Therefore, improving reliability is a win-win situation for both users and transit agencies and enables cities to achieve broader environmental and social goals.

Lively discussions concerning the importance of reliability for passengers can be found throughout the literature. Peek and Van Hagen (2002) applied Maslow's pyramid to transportation planning to represent passengers' priorities. This approach argues that safety and reliability form the foundation of traveller satisfaction and, accordingly, must be provided without creating doubt among users. The upper part of the pyramid includes additional aspects of quality such as comfort. Hensher, Stopher and Bullock (2003), and Brons and Rietveld (2007), among others, later confirmed this important prioritization for both regular users and non-regular users. Other research has shown that reliability is the second most important transit attribute, behind arriving safely at destinations (Iseki & Taylor, 2010; Perk, Flynn, & Volinski, 2008; Taylor, Iseki, Miller, & Smart, 2007).

Aside from other issues, factors affecting the concept of reliability are not equal across transportation modes. Bus transit systems are more exposed to different expected and unexpected factors such as traffic congestion, weather and demand fluctuations, all of which challenge the required level-of-service quality. It is well-established that, regarding bus operation, the targeted level of service is usually different from both the level actually delivered and the level expected and perceived by passengers (Vuchic, 2005). Furthermore, fixed-route bus transit systems are the dominant form of public transportation in most cities in the U.S. and Canada, providing an important means of mobility to the public.

Findings from the American Public Transportation Association (APTA) (2011a) indicate that in 2009, around 10.2 billion unlinked trips were made using various types of transit service, with 34% growth compared to 1995, which is more than twice the growth rate of the U.S. population (15%) over the same period. Bus services comprised more than 52% of these trips compared to all other modes (e.g. commuter rail, light rail, paratransit, vanpool, trolleybus, etc.). On the other hand, over the same period, the amount of annual delay caused by traffic congestion increased by 4 hours per commuter (Schrank, Lomax, & Eisele, 2011), which affects the bus transit systems that share the same road space.

In Canada, public transit share increased steadily by 4.6% between 2002 and 2011 to reach around 2 billion trips, while the average annual population growth rate is only around 1% (Index Mundi, 2012; Statistics Canada, 2008). It should be noted that a spike in unemployment in 2008 and the decline in gas prices in 2009 did not reverse the increasing trend in transit service ridership, which confirms that transit operators have been able to attract and keep riders, particularly the choice riders (Canadian Index of Wellbeing, 2012).

Transit systems serving populations over 1.5 million, namely in Montreal, Toronto, and Vancouver, had an overall ridership increase of 4.2%. 4.8%, and 6.6% between 2010 and 2011(Canadian Urban Transit Association (CUTA), 2011). It is further important to note that in these three cites, urban buses represent the main form of transport, comprising around 55%, 51% and 66% of Montreal, Toronto, and Vancouver transit ridership in 2011, respectively (American Public Transportation Association, 2011b; TransLink, 2011). Between 1994 and 2011, the average daily commuting time for working Canadians increased by 11 minutes per day (from 42.6 minutes to 53.2 minutes), representing approximately 45 hours per year or a week’s worth of work time. This increase occurred, to a certain extent, due to a higher volume of traffic congestion (Canadian Index of Wellbeing, 2012). In short, although bus transit systems are the dominant form of mobility in our cities, transit agencies are facing many challenges in operating these systems in an efficient and reliable manner. Therefore, transit agencies must develop several strategies to meet these challenges in order to attract new passengers and retain existing ones.

1.4 RELIABILITY FROM A THEORETICAL PERSPECTIVE

What is reliability? It is a term commonly used by laypersons and researchers, but what does it really mean? People use the word “reliable” in everyday language to provide an indication or a signal about something they perceive. For instance, people often describe a good machine or an efficient car as reliable. Or, media people might describe an informant as a reliable source. In both cases, the word “reliable” usually means *dependable* or *trustworthy*. In engineering sciences there is a well-established theory called the “theory of reliability,” which refers to any system that consistently produces the same results, rather than meeting, or even exceeding, expectations (Trochim & Donnelly, 2006).

In the transportation setting, there is a wide range of definitions for the concept of reliability. It can be defined as the invariability of transit service attributes at certain locations, affecting people and operators’ decision-making (Abkowitz, Slavin, Waksman, Englisher, & Wilson, 1978; Cham, 2006). According to this definition, a discussion of reliability integrates the perceptions of users and operators. Reliability can also be defined in terms of performance measures. Kimpel (2001) defined it as “a multidimensional phenomenon in that there is no single measure that can adequately address service quality” (p.8). Different measures have been identified by researchers and range from minimizing schedule delays, running time delays and headway delays to achieving on-time performance (OTP) standards (Kimpel, 2001; Strathman et al., 1999; Turnquist, 1981). OTP refers to the acceptable, predetermined range of delays or early arrivals for a vehicle; while headway is a measurement of the time between vehicles in a transit system.

Other definitions combine reliability measurements with passengers’ perceptions. For example, according to the Transit Capacity and Quality of Service Manual (TCQSM) (2003), reliability encompasses both OTP and the regularity of headways between successive transit vehicles, which affects travellers' perceptions. Here, the TCQSM incorporates various comments that represent users' experiences in relation to each level-of-service (LOS) quality grade. For example, in LOS "C," passengers experience more than one late vehicle per week on average. Within this framework, OTP is defined as on-time when a vehicle arrives less than five minutes behind schedule and no more than zero minutes early at a stop. In this framework of definitions, there is a lively and expanding body of literature which debates the right measures to address service reliability. Xin et al. (2005) used the TCQSM Measures, and indicated that TCQSM measures are suitable for understanding reliability. On the other hand, Camus et al. (2005) discussed the limitations of the TCQSM's OTP method since it introduces a fixed tolerance for the schedule to estimate the on-time performance and proposed a new measure named Weighted Delay Index. Subsequently, other researchers have proposed different measures to deal with the shortcomings of the TCQSM framework in order to better understand service reliability (Fu & Yaping, 2007; Lin, Wang, & Barnum, 2008; Saberi, Zockaie, Feng, & El-Geneidy, 2012). Still other researchers have used a holistic standpoint to define reliability from the passengers' perspective. Passengers perceive the service as reliable when it (a) decreases their efforts to access the service, (b) has short and consistent travel times, and (c) arrives predictably, resulting in short waiting times (El-Geneidy, Horning, & Krizek, 2011; Koenig, 1980; Murray & Wu, 2003).

1.5 THE ERA OF AUTOMATIC DATA COLLECTION

Improving reliability requires accurate and comprehensive data about operation and usage of transit vehicles (bus load and demand) and networks (Mistretta, Goodwill, Gregg, & DeAnnuntis, 2010). According to Levinson (2005) improving reliability efforts began in the first half of the twentieth century by monitoring the service using both manual labour and mechanical devices. However, these methods were not efficient and were extremely expensive, requiring transit agencies to make strategic decisions based on small datasets, since most transit agencies preferred to direct their funds towards providing more service, rather than data collection (Fielding, 1987). By 1990, the emergence of new technologies of automatic data collection provided the operators with a window of hope to systematize and restructure service schedules based on the special characteristics of each route (Strathman et al., 1999). Buses were equipped with Automatic vehicle locations (AVL) systems capable of storing and sending continuous, immediate and accurate detailed data with regard to bus location, number of stops, and travel time. Meanwhile automatic passenger counting (APC) systems coupled with AVL to collect data related to the number of boarding and alighting passengers. Soon after the introduction of these systems, many transit agencies around the world adapted them (H. Levinson, 2005; Radin, 2005).

In fact, these automated data collection systems have transformed the data environment for transit agencies, proving a rich source of accurate information, and facilitating an extensive and detailed analysis of transit operations. Recent evidence shows that these new technologies have significantly improved operators' performance and reliability at a reasonable cost, offering passengers more punctual, adequate service (Diaz & Hinebaugh, 2009; Strathman, Kimpel, & Callas, 2003). For example, according to the Maryland Department of Transportation (2011), the implementation of AVL technology on buses in 2009 increased the agency OTP from 73% in 2009 to 87% in 2010, reflecting people's overall satisfaction with the service. This technology has also helped to monitor and adjust bus schedules and routes in order to achieve more efficiency, which has reduced operational costs. One of the main challenges now is figuring out how to utilize these rich data sources to improve decision making and transit service planning.

1.6 GAPS IN KNOWLEDGE

Transit agencies employ several strategies in order to enhance their performance, while considering their value, possible constraint and overall impact on passengers. Previous literature reviews have focused on either passengers' or transit agencies' perspectives on service reliability (Benn, 1995; Carrion & Levinson, 2012; Mistretta et al., 2010). However, none of the earlier reviews have simultaneously addressed these differing perspectives on service reliability in an integrated manner. By failing to do so, the existing literature cannot identify the areas of overlap and disconnect between the two perspectives regarding service reliability and the impact of service improvement strategies. The areas of disconnect represent important gaps in understanding that need to be addressed to enable transit agencies to achieve better service that is positively perceived by passengers.

Several strategies are employed by transit agencies in order to provide an attractive transportation service. These strategies include using low-floor buses, articulated buses, reserved bus lanes, intelligent transportation systems (ITS), limited-stop service, bus rapid transit (BRT), and BRT-like systems (Schramm et al., 2010; Tann & Hinebaugh, 2009). In fact, the body of literature covering these strategies has been achieved by investigating the effect of only one or two strategies intended to improve a service, which hardly provides a comprehensive analysis for measuring the impact of implementing a set of measures at once. Hence, it has been executed using simulation approaches (Abkowitz & Engelstein, 1983; Attoh-Okine & Shen, 1995; Dessouky, Hall, Zhang, & Singh, 2003), or statistical analysis for before-and-after data for short periods of time (El-Geneidy & Vijayakumar, 2011; Furth & Muller, 2006, 2007). Nevertheless, in reality, transit agencies often combine various measures that are employed by BRT systems, such as transit signal priority (TSP), reserved bus lanes and articulated buses, in order to provide better service, since these systems are considered the most effective tools to increase service reliability, efficiency and ridership (Currie, 2006; The Canadian Urban Transit Association (CUTA), 2007). Therefore, much more work is needed to understand the impact of implementing a set of combined measures designed to improve the bus transit service and to demonstrate how these measures may function together in affecting the service and its reliability.

While several researchers have investigated the effect of each different strategy on service running time (Kimpel, 2001; Strathman et al., 2000; Strathman, Kimpel, Dueker, Gerhart, & Callas, 2002; Surprenant-Legault & El-Geneidy, 2011), less attention has been paid to the impact of different strategies on variations in service, which is more difficult to address (Schramm et al., 2010). Further investigation on the effect of different transit service improvement strategies on variation is essential. On the other hand, while transit agencies are applying different measures to improve their service, understanding the change in passenger perception over time is a topic rarely presented in the literature (Diab & El-Geneidy, 2014). More specifically, researchers and transit agencies generally indicate that people are more satisfied after the introduction of an improvement strategy (Cain, Van Nostrand, & Flynn, 2010; Conlon, Foote, O'Malley, & Stuart, 2001; Currie, 2006; El-Geneidy & Surprenant-Legault, 2010). Nevertheless, this tendency to be more satisfied has not yet been quantified. Again, the question of the extent to which passengers overestimate their benefits in terms of their waiting and travel time, and how these estimations change over time is hardly presented in the literature. This relationship between perceived values and objective measures may give us insight into how travellers perception of reliability is related to the decision making process. A detailed discussion of the above mentioned gaps is presented in the second chapter of the dissertation. The following section will detail how I propose to address those gaps.

1.7 RESEARCH GOAL AND OBJECTIVES

My PhD research aims to develop ways of addressing, examining, and understanding the fundamental questions about how transportation planning and operations can better serve and provide users with a more reliable and better perceived service. My research goal is *to provide a reliable service that is positively perceived by transit users.* This goal can be achieved by answering the following main research question: *What are the effects of various improvement strategies on bus transit service delivery and on users' perception?* Specifically, my research addresses the following research questions:

- What are the areas of overlap and disconnect in understanding between the transit agencies and passengers regarding service reliability and the impacts of service improvement strategies?
- What are the benefits of implementing more than one improvement strategy for transit agencies? What will the passengers' immediate response to those strategies be?
- What are the impacts of implementing various improvement strategies on bus transit service variation?
- How do passengers' responses to those strategies change over time in terms of their estimation of their time savings?
- How can these findings be used to improve public transport planning and decision-making in the future?

These five research questions represent the detailed research objectives. By addressing these issues, this work will explore an important gap in the current understanding of the relationship between transit agency' and passenger' perceptions, and how that affects the implementation of strategies. In fact, the availability, affordability and accuracy of AVL/APC systems' data now offers an excellent opportunity to analyze the actual operational data, conceptualize and understand the impact of different improvement strategies on the service as well as on people's perceptions, providing planners and decision makers with effective and valuable policy-relevant information that can be used to improve transit systems. Furthermore, Canada—and Montreal in particular—with the extensive efforts which have been made to promote public transit that have led to a constant increase in the public transit mode share, offers an interesting setting for an exploration of these issues. This section details each of the following chapters with respect to how they address different aspects of the above-detailed questions and concerns. Figure 1.1 provides an illustration of the structure of the dissertation and the relationship between the various parts. The following section (Section 1.11) offers additional details about each chapter.

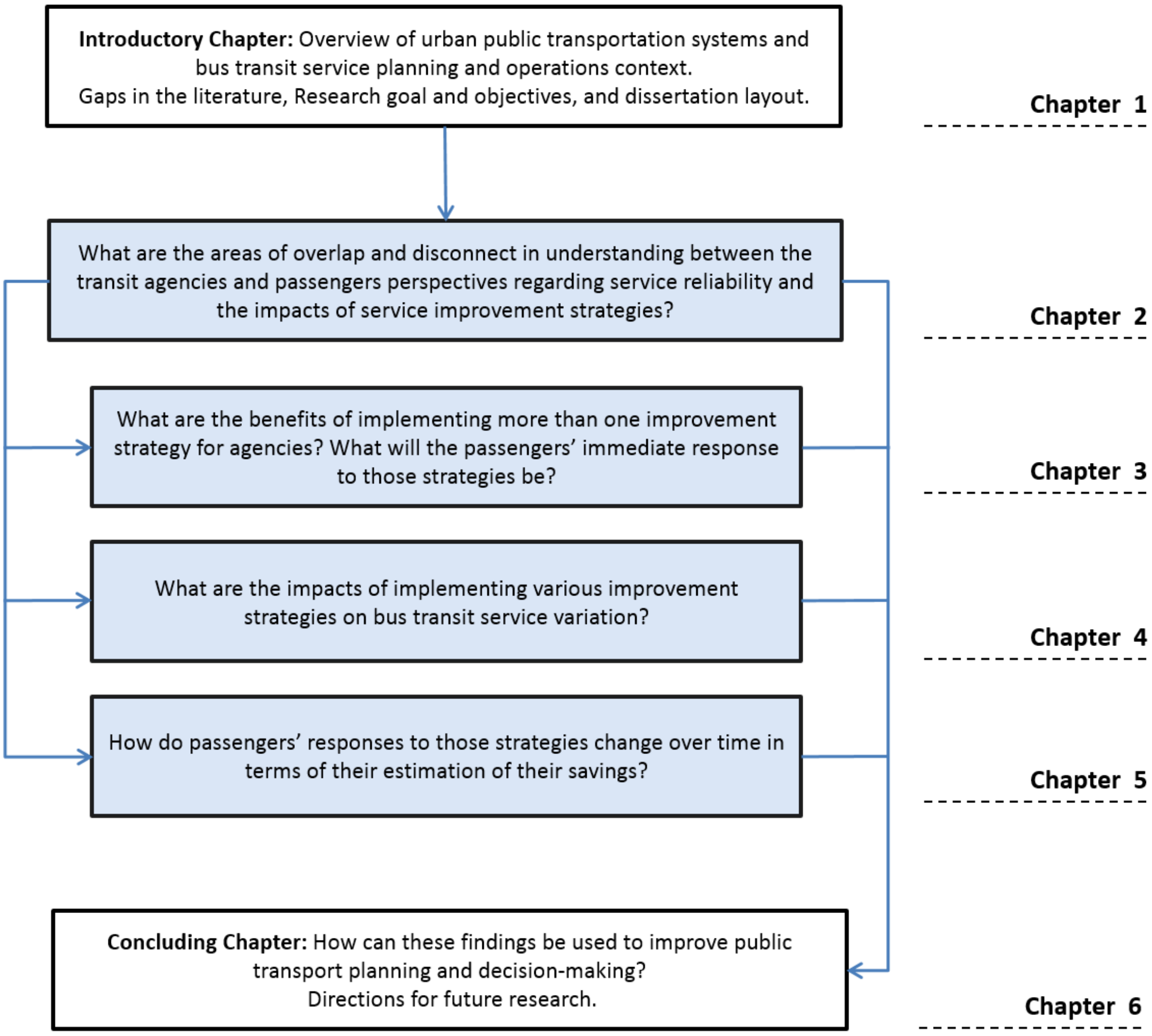


Figure 1.1 Schematic diagram of workflow and conceptual links

1.8 DISSERTATION STRUCTURE AND OVERVIEW OF CHAPTERS

My research will be structured in such a way as to follow McGill University guidelines for a manuscript-based dissertation. This dissertation comprises four manuscripts that address the themes and research objectives outlined in the previous sections. Each chapter contains a brief overview section prior to the manuscript text. Each chapter has a separate introduction and literature review followed by a methodology section to describe the data, study context and the quantitative and qualitative research methods adopted. Chapter six summarizes the findings and contextualizes them in terms of broader research objectives. The chapter concludes with details about the contributions to knowledge and highlights directions for future research. I will briefly introduce each chapter below.

The second chapter is primarily a literature review that uses a set of qualitative methods and research techniques. Passengers and transit managers and officials can have strong and sometimes conflicting ideas about what makes a good and reliable service. The task of integrating and reconciling these perspectives poses difficult challenges, because the understanding of passengers’ perception is usually gleaned in isolation from a transit agency perspective, and the impact of transit improvement decisions have intangible and hard to quantify outcomes. Previous literature reviews have focused on either passengers’ or transit agencies’ perspectives on service reliability. However, none of the earlier reviews have simultaneously addressed these differing perspectives on service reliability in an integrated manner. In response to this gap in the literature, this chapter first reviews previous work on passengers’ perspectives of transit service reliability and the response to service adjustments made by different agencies. Second, it analyzes transit agencies’ plans and reports regarding the goals and strategies used in order to improve service reliability, while looking at the impact of these strategies on service. Reviewing these two parts together provides a needed contribution to the literature from a practical viewpoint, since it allows for the identification of gaps in the public transit planning and operations field in the area of reliability and provides transit planners and decision makers with effective and valuable policy-relevant information.

In response to the identified gaps in the literature alluded to in the second chapter, I have conducted three empirical studies to address some of the keys regarding the impact of service improvement strategies on transit service performance and passengers' perception, using a unique case study from Montreal, namely the Saint-Michel bus corridor. Saint-Michel is a heavily used bus corridor located to the east of Montreal's central business district, in the province of Quebec, Canada. In an attempt to improve transit service on the island, Société de transport de Montréal (STM), the transit provider on the island of Montréal, has implemented a series of strategies over a period of three years. These strategies include using smart card fare collection, introducing limited-stop bus service, implementing reserved bus lanes, using articulated buses, and adopting transit signal priority (TSP).

Chapter 3 develops methodologies to deepen the understanding of the collective impact of strategies and the synergies between them on transit system running time and on users perception, using approximately 2,270,000 stop-level observations collected from the STM's automatic vehicle location (AVL) and automatic passenger count (APC) systems, as well as a field survey carried out among 354 users. While the majority of literature covering transit agencies improvement strategies has been done by investigating the effects of one or two strategies meant to improve the service, this chapter presents original information concerning the collective impact of strategies and the synergies between them, which is presently absent from the literature. This chapter is related to the current practice of transit agencies, which often combine multiple strategies to achieve better service, as in the case of Saint-Michel, without a clear understanding of the effects of synergies between strategies on the quality of service. The second objective of this chapter is to quantify to what extent users perceive STM’s implemented strategies and their effects on travel time. This link between the quantitative measures of service and the perceived value provide us with valuable information that in particular points out how they overestimate (or underestimate) their travel time benefits.

Chapter 3 also investigates the overall impacts of a set of strategies on running time at the route level, which was one of the main goals these strategies were developed to achieve. Although this information presents one important part of the picture, it ignores any side effects that given strategies might have on variation in the service. The effect of these strategies on service variation is an important aspect of service provision. Transit agencies pay a lot of attention to variation of transit service since that variation directly affects the amount of recovery time added to schedules and service productivity. Transit agencies are also interested in providing reliable service that is fast and consistent from day to day to increase passenger satisfaction. Therefore, Chapter Four examines the impact of the previous improvement strategies implemented by STM on running time deviation from schedule, variation in running time, and variation in running time deviation from schedules along the Saint-Michel bus corridor. This study uses AVL/APC systems data in order to offer transit agencies and planners a unique understanding of the effects of various strategies on different aspects of service variation, which are important components of transit service reliability that are rarely discussed in the literature. In this chapter, several key questions regarding the impact of service improvements strategies on transit service reliability will be answered.

Chapter 3 focuses on measuring users’ perception and satisfaction immediately or at a specific point in time after the implementation of STM strategies. However, this information presents only one important aspect of the truth, since transit agencies are interested not only in seeing that users are satisfied at a given juncture of their travel time, but also in keeping users pleased with the quality of service provided over time. Therefore, a more detailed understanding germane to what extent users overestimate their time savings and how these estimated perceptions can change over time is needed. This is an important policy-relevant issue, since agencies should understand the quantitative effects of their strategies not only on system performance, but also on user’s perceptions, which is covered in Chapter Five. The chapter analyzes three surveys of bus user perceptions conducted over a period of three years. It also uses stop-level data collected from the STM’s AVL/APC systems and bus schedules to control for the actual changes in service. In this chapter, I use descriptive statistics and regression models to help in better understanding the differences between perceptions and reality. This chapter elaborates on the existing literature and current practice, both of which ignore a range of temporal impacts that strategies may have and the differences between the effects of strategies on perception. It provides transit agencies’ marketing and planning departments with important and comprehensive insights regarding passengers’ perception following the implementation of service improvement strategies.

2 CHAPTER TWO: BUS TRANSIT SERVICE RELIABILITY AND IMPROVEMENT STRATEGIES: INTEGRATING THE PERSPECTIVES OF PASSENGERS AND TRANSIT AGENCIES IN NORTH AMERICA

2.1 OVERVIEW OF CHAPTER

Passengers, transit managers, and government officials can have strong, and sometimes conflicting, ideas and thoughts about what makes a good and reliable service. The task of integrating and reconciling these perspectives poses difficult challenges, because the understanding of passengers' perception is usually done in isolation from transit agencies' perspective, also that the impact of transit improvement decisions have intangible and hard to measure outcomes. Therefore, I first use a systemic review method to identify the international literature that covers the passengers' perspective of transit service reliability and their response to service adjustments made by different agencies. Second, I analyze transit agencies' plans and reports for fifteen transit agencies from North America regarding their reliability goals and the strategies employed in order to improve service reliability, while looking at the impacts of these strategies on service. Then, I identify the areas of overlap and disconnect and mismatch in understanding between both perspectives (i.e. transit agencies and passengers) regarding service reliability and the impact of service improvement strategies. The areas of disconnect represent the important gaps in understanding in need to be integrated and addressed to enable transit agencies to achieve better service that is positively perceived by passengers.

Reviewing these two parts together provides a needed contribution to the literature from a practical viewpoint since it allows for the identification of gaps in the public transit planning and operations field in the area of reliability and the use of improvement strategies. The chapter indicates that there are several key differences between both perspectives in terms of the definitions of reliability, the standard viewpoint regarding OTP, and the unaddressed service variation issues. It also indicates that the focus of the current literature does not match the knowledge needs of transit agencies regarding the impact of various improvement strategies on transit service reliability and on users' perceptions, which might be inhibiting the transit agencies' ability to correctly anticipate the impact of their planning improvement decisions. Finally, this chapter provides a theoretical and intellectual base for the following chapters of my dissertation. It should be noted that this chapter was written and updated after the publication of the third and fourth chapters. Therefore, these chapters are included in the literature review section.

2.2 INTRODUCTION

Public transit systems are essential services to the sustainability, equity, and livability of any city. In fact, during the past decade, transportation planning has shifted its focus from car mobility goals to embrace broader environmental and social goals, in particular, by providing and improving transport alternatives that provide access to destinations regardless of car ownership (Jabareen, 2006; Lucas et al., 2007). This shift in paradigm has encouraged operators to incorporate various strategies to improve transit service operation with the goal of attracting new passengers and retaining existing ones. This shift is supported by enormous funding commitments from federal, state and local governments in order to improve transit service. For example, in the United States, total government spending increased at an annual average inflation-adjusted rate of about 3% between 1997 and 2012, from $26.1 billion to $ 58.5 billion (NTD, 2013).

Transit agencies are responsible for providing an efficient, productive and reliable service that is positively perceived by the public (Vuchic, 2005). It is clear that providing a reliable transit services is necessary in order to maintain an efficient and attractive system, which increases users' satisfaction and loyalty. Reliability is also important for operators because it can easily improve internal efficiency, reduce operating costs, and improve revenues by retaining and attracting users. Therefore, improving reliability is a win-win situation for both users and transit agencies and enables cities to achieve their broader goals. The present review of the literature aims to understand transit service reliability from different perspectives. More specifically, it attempts to identify passengers' and transit agencies' perspectives, while linking both perspectives to empirical studies that investigate the impacts of service improvement strategies. This chapter uses a systemic review method to identify the international literature that covers the passengers' perspective, while analyzing North America's transit agencies' perspectives regarding service reliability.

Within the transportation setting, there are a wide range of definitions for the concept of reliability. It can be defined as the availability and stability of transit service attributes at certain locations, affecting people and operators' decision-making (Abkowitz et al., 1978; Cham, 2006). On the other hand, reliability can also be defined in terms of performance measures. Kimpel (2001) defined it as "a multidimensional phenomenon in that there is no single measure that can adequately address service quality." (p. 3) Different measures have been identified by researchers and range from minimizing schedule delays, running time delays and headway delays to achieving on-time performance (OTP) standards (Kimpel, 2001; Strathman et al., 1999; Turnquist, 1981). Other researchers used a holistic standpoint to define reliability from the passengers' perspective. Passengers perceive the service as reliable when it (a) decreases their efforts to access the service, (b) has short and consistent travel times, and (c) arrives predictably, resulting in short waiting time (El-Geneidy et al., 2011; Koenig, 1980; Murray & Wu, 2003).

Researchers argue that public transport patronage growth can result from service reliability improvements, whereas it can decay due to unreliable service (Bates et al., 2001;

Nam et al., 2005; Noland & Polak, 2002; Vuchic, 2005). A lively discussion about the importance of reliability issues for passengers can be found throughout the literature. Peek and Van Hagen (2002) suggested an approach based on Maslow's pyramid, which represents passengers' priorities. This approach argues that safety and reliability are the foundation of traveller satisfaction, and accordingly, must be provided. The upper part of the pyramid includes additional aspects of quality such as comfort. Hensher, Stopher and Bullock (2003), and Brons and Rietveld (2007) confirm this hierarchal importance of prioritization for both regular and non-regular users. Other researchers have argued that reliability is the second most important transit attribute after arriving safely at destinations (Iseki & Taylor, 2010; Perk et al., 2008; Taylor et al., 2007; Yoh, Iseki, Smart, & Taylor, 2011).

2.3 METHODOLOGY

This section describes the methodology used in the analysis, and contains two sections. The first section describes the review of academic literature concentrating on the passengers' perspective and reliability improvement strategies, while the second section focuses on the analysis of transit agencies' plans and reports in order to understand their perspective.

2.3.1 Literature Review

A systematic literature review is an important and useful approach to identify and analyze all relevant research on a given topic. The present study uses a Realist method to understand the literature concerning: (a) passengers' perspective, and (b) reliability improvement strategies. This method builds on the conventional systematic review template to provide a more explanatory rather than a solely judgmental focus (Pawson, Greenhalgh, Harvey, & Walshe, 2005). For each section of the literature review, a search strategy consisting of two phases is conducted. The first phase includes a search of the Web of

Knowledge, Scopus and TRID online article databases in November of 2013. TRID is a comprehensive database that includes more than one million records of transportation research worldwide (TRID, 2013). Only results yielding full articles and papers are included in the analysis. Additionally, the search is also restricted to include only publications in English related to transportation, urban studies, social sciences and engineering. There were no date restrictions on the results of the search. The second phase of the search strategy began once the database search had identified the relevant articles based on a predetermined set of inclusion and exclusion criteria. Table 2.1 shows the criteria. The reference lists of all articles were examined, and articles found through this method were subject to the same exclusion criteria after their full texts had been read.

2.3.1.1 Passengers' perspective

The search consisted of the following terms within the ‘‘title’’ search field: *“(Bus OR Transit) AND perception or time value”, OR “(bus OR transit) AND satisfaction or demand or ridership.”* The first phase of the search yielded 340 papers in total, of which 316 were excluded due to irrelevance and application of exclusion criteria. The second phase of the search strategy began once the database search results had been reduced to 22 relevant articles based on the predetermined set of exclusion criteria. Then, the reference lists of all articles were examined and yielded an additional seven articles. Finally, articles that passed this review process were read in their entirety (see Table 2.2). The studies range in publishing date from June 1987 to November 2013. The studies selected for the review focused on one or more aspects of transit users’ point of view in terms of their perception, estimation of their time value, demand and satisfaction.

2.3.1.2 Reliability improvement strategies

The search consisted of the following terms within the ‘‘title’’ search field: "(Bus OR Transit) AND improvement strategies or Automatic data collection or AVL or APC or AFC” OR "(Bus OR Transit) AND Reliable or Reliability or On-time performance”, OR"(Bus OR Transit) AND travel time or dwell time.” The first phase of the search yielded 230 papers in total, of which 218 were excluded due to irrelevance and application of exclusion criteria. Studies using the actual automatic operational data e.g. extracted from Automatic Vehicle Location (AVL) and Automatic Passenger Counting (APC), and Automated Fare Collection (AFC), were included if the results were based on empirical model-driven analyses. Strathman and Hopper (1993) demonstrate the importance of the emergence of these automatic data collection technologies in the 1990's. They provide researchers and agencies with a rich and accurate source of information, facilitating extensive and detailed analysis of transit operations (Feng & Figliozzi, 2011; Furth, Hemily, Muller, & Strathman, 2006; Furth & Muller, 2007; Hickman, 2004; Peng, Lynde, & Chen, 2008; Uniman, Attanucci, Mishalani, & Wilson, 2010) . The second phase of the search strategy was based on the reference lists of the 12 relevant articles and yielded one additional article. Table 2.4 presents these studies. The studies range in publishing date from June 2000 to July 2013. Findings from these studies are discussed in the transit agencies’ perspective section following the introduction of what measures agencies use to improve the service.

Table 2.1: Inclusion and exclusion criteria for literature review

Inclusion criteria	Exclusion criteria
Passengers' perspective	
• Uses surveys or real-world observations • Focuses on passenger-related issues (i.e. demand, perception, satisfaction and time value) • Investigates the factors impacting passengers' perception. • Empirical analysis • Published up to November 2013 • Peer- reviewed • Full articles only • English language only	• Focuses on private automobile • Focuses on other public transport modes, e.g. trams and trains, planes, undergrounds, and ferries • Focuses on vehicle emissions and economics, and users' life satisfaction issues • Focuses on simulation techniques and mathematical optimizations methods. • Not peer reviewed • All languages other than English
Reliability improvement strategies*	
• Uses automatic data collection (e.g. AVL, AFC, APC) • Analyzes the impact of improvement strategies (e.g. bus type, reserved lanes, TSP ...etc) • Focuses on one of the service operational aspects (e.g. running time, on-time performance, dwell time) or their variation • Empirical model-driven analyses • Published up to November 2013 • Peer- reviewed • Full-articles only • English language only	• Focuses on private automobile • Focuses on other public transport modes, e.g. trams and trains, planes, undergrounds, and ferries • Focuses on vehicle emissions and contracting • Focuses on simulation techniques, mathematical optimizations methods and visualization • Only a summary statistics study • Not peer reviewed • All languages other than English

* AVL: Automatic Vehicle Location, APC: Automatic Passenger Counting, AFC: Automated fare collection, TSP: Transit Signal Priority System

2.3.2 Transit Agencies' Plans

The existing literature rarely discusses how transit agencies define and resolve reliability issues or realize their reliability objectives and employ strategies to achieve these objectives. Previous studies focus solely on aspects such as understanding transit agencies' performance measures (Bates, 1986; Benn, 1995; Kittelson & Associates, Urbitran, et al., 2003), employing archived AVL/APC data to improve transit performance and management (Furth et al., 2006), or planning processes (Mistretta et al., 2010). This section reviews 15 of the largest bus transit agencies' plans and reports in the U.S. and Canada, which are ranked by annual ridership (American Public Transportation Association, 2011a, 2011b). The search criteria regarding plans and reports were as follows: large transit agencies with recent documents published after 2004 available from an agency’s official website. Table 2.3 shows the results of transit agencies’ plans that were reviewed.

Transit agencies’ plans and reports represent one of their main outputs illustrating their guidelines, policies and approaches, and are used to communicate these to the public. The purpose of this approach is not only to understand their performance measures, but also to understand the main reliability goals these agencies articulated, and strategies they use to achieve them. The idea of transportation plan analysis and examination is well established in the literature. Researchers have employed this approach to understand existing policies regarding various goals, including agencies’ sustainability orientations and approaches, or their social goals (Berke & Conroy, 2000; Feitelson, 2002; Geurs, Boon, & Van Wee, 2009; Stanley & Villa-Brodrick, 2009).

Finally, the study identifies the areas of overlap in understanding as well as the areas of disconnect and mismatch between the two perspectives (i.e. transit agencies and passengers) regarding service reliability and the impacts of service improvement strategies. The areas of disconnect represent the important gaps in understanding that need to be integrated and addressed to enable transit agencies to achieve better service that is positively perceived by passengers.

2.4 PASSENGER PERSPECTIVES

2.4.1 Passengers’ Time Value

A sizable body of literature has solely developed around how users value their time during a transit trip and has attempted to assign a dollar value to passenger time, with an underlying assumption that the value of time is equal to its opportunity cost, usually defined as the wage rate (Wardman, 2004). These studies tend to focus on the relationship between out-of-vehicle time and in-vehicle time. For example, Mohring et al. (1987) estimate the value associated with in-vehicle time as half of an hourly wage whereas waiting time is valued at a level two to three times that of in-vehicle time. One example is Wardman's (2001) study that uses a regression model to analyze evidence drawn from 143 British academic and consultancy studies conducted between 1980 and 1996. He estimated that walking time, waiting time, and combined walking and waiting time are respectively valued 1.66, 1.47, and 1.46 times as much as in-vehicle time. Later, Wardman (2004) suggested that previous estimations for waiting time values were too low, and it is reasonable to value waiting time at 2.5 times as much as in-vehicle time. However, some studies he referenced indicated that the waiting time is valued up to 4.5 times more than walking time, which is valued at two times that of in-vehicle time. Similarly, several studies reviewed by Reed (1995) indicate a significantly different estimation for waiting time value, ranging from less than 1.5 times to as much as 12 times that of travel time value. It is important to note that the calculated values of waiting time vary by income, location, trip distance and purpose, and by survey method (Abrantes & Wardman, 2011; Chang & HSU, 2003; Lam & Morrall, 1982; Wardman, 2004). Shires and de Jong (2009) indicate similar factors that impact the value of travel time savings. However, it is rare to find empirical studies in the literature investigating the value of time savings that come as a result of service improvements.

Nevertheless, from the perspective of behavioural decision research, the value of time is subject to context effects. Most human behaviour is analogous in its relation to both time and money; however, it differs completely for all situations involving risk (or uncertainty) (Leclerc, Schmitt, & Dube, 1995). Behavioural decision researchers more recently have extended the previous argument in the context of time versus money and state that there are quantitative and qualitative differences in how people process temporal information in relation to monetary information to arrive at judgments and decisions (Monga & Saini, 2008; Soman, 2001; Zauberman & Lynch, 2005). While most of the studies regarding the cost of travel time reliability focused on car users' perception (Carrion & Levinson, 2012; C. Chen, Skabardonis, & Varaiya, 2003; Z. Li, Hensher, & Rose, 2010; Small, Noland, Chu, & Lewis, 1999), it is rare to find studies focused specifically on transit users. One example is an empirical analysis by Pinjari and Bhat (2006) which indicates that transit passengers, during the first 15 minutes of a trip, place a small value on travel time while placing a higher value on travel time reliability. However, the value of travel time increases rapidly after the first 15 minutes while the valuation of travel time reliability falls radically.

2.4.2 Passengers' Time Perception

Research indicates that passengers perceive waiting time differently from the actual time for reasons such as being exposed to adverse weather conditions, the surrounding environment and the experience of being stressed by waiting anxiety (Daskalakis & Stathopoulos, 2008). Mishalani et al. (2006) used linear regression to investigate the relationship between passengers' perceptions of waiting time and actual time. In this study a surveyor went to a bus stop, noted the arrival time of a passenger, and then asked him or her about their time perceptions. The results of this study indicate an overestimation of waiting time by 0.84 minutes. Psarros et al. (2011) used the same data collection technique and revealed that for all trip purposes – work, education, shopping and personal affairs – users overestimated their waiting time by 27%, 43%, 30% and 30%, respectively, comapred to actual waiting time. However, these estimates may not present the actual case because perception of waiting time tends to differ significantly from the actual measured waiting time depending on whether passengers make a conscious decision to wait compared to when the wait is imposed on them by others, such as transit agencies (Moreau, 1992).

Hall (2001) indicated that passengers who knew the schedule were more inclined to believe the bus was late than those who did not know the schedule. Hess, Brown and Shoup

(2004) report that passengers overestimate their waiting time by a factor of two compared to the actual wait time when it is imposed by others (e.g. transit system) whereas they accurately estimate their waiting time when they themselves chose to wait (e.g. for a free bus). Other researchers indicate that this tendency to overestimate waiting time is further affected by the individual's personal experience in terms of whether the passenger is experiencing *time drag* or not. Time drag occurs when a passenger perceives his time spent at a stop as unproductive and useless, which occurs when the passenger is not involved in other activities such as reading a book while waiting. In this case, waiting time can seem much longer (Dziekan & Vermeulen, 2006; Moreau, 1992; Reed, 1995). However, no study explicitly focused on understanding the impacts of bus delay or arrival variation on transit users' waiting time perception.

Regarding travel time perception, the Transit Capacity and Quality Service Manual (TCQSM) (2003) suggests that perceived travel time is equal to actual travel time. However, this does not provide understanding about how passengers perceive travel time variability, which is clearly an added time cost that passengers must account for during their trip planning (Daskalakis & Stathopoulos, 2008). According to the scheduling approach theory, transit users' preferred departure time would change (later or earlier) in response to transit schedule constraints and structures and their perceptions about travel time variation. Hollander (2006) confirms that the impact of travel time variability on passengers is best explained through scheduling considerations. Nam et al. (2005) indicates that, at the same level of improvement, policies designed to decrease travel time variability are more beneficial than policies designed to reduce travel time. In addition, there is some empirical evidence that suggests there is an inherent disutility associated with a failure to adhere to the schedule for both the early and the late arrival, particularly if there is a transfer point in the trip (Bates et al., 2001; Noland & Polak, 2002). In other words, arriving early at destinations (e.g. a transfer point) is not as good as arriving late because time cannot be restored and used for other purposes, and users will regard the time spent due to the early arrivals as a wasted time that they may have used better if they had taken the following trip instead. In short, passengers overestimate their waiting time at bus stops and value this waiting time more than any other time component of their trip.

2.4.3 Transit Strategies Impact on Passengers' Perception

A number of studies examined the immediate impact of the implementation of different strategies on users' perceptions, and they generally indicated that passengers tend to perceive the service more positively after the implementation of a new strategy (Cain et al., 2010; Conlon et al., 2001; Currie, 2006; El-Geneidy & Surprenant-Legault, 2010). For instance, using a before-and-after rating system survey in Chicago after the implementation of a limited stop service running parallel to a bus route, users indicated a high satisfaction level in many areas including the overall satisfaction, satisfaction of travel time and waiting time, at both the regular and the limited stop service routes (Conlon et al., 2001). Dziekan & Vermeulen (2006), Dziekan & Kottenhoff (2007) and Watkins, et al. (2011), among others, have investigated the impact of the introduction of real-time information on passenger' waiting time perception. Results from these studies indicated that the perceived waiting time decreased after the implementation, without reporting any actual improvement in the service frequency. El-Geneidy & Surprenant-Legault (2010) focused on users' travel time perception after the implementation of a new limited stop service, indicating that users overestimate their perceived travel savings compared to the actual time savings.

Cain, et al.(2010) revealed that the implementation of express lanes significantly improved users' travel time and service reliability ratings. Diab & El-Geneidy (2012) investigated the impact of a combination of strategies on passengers' travel time perception, indicating that passengers tend to overestimate the travel time savings associated with the implementation of this combination of strategies, while there was almost no actual saving in buses' running time in some cases. This indicates a positive attitude toward the implementation of improvement strategies. However, previously mentioned studies in this subsection focused on measuring users' perceptions and/or satisfaction immediately (at one time point) after the implementation of a new measure or route. Thus, it is rare to find studies that investigate how these perceptions change over time. Only Dziekan & Vermeulen (2006) investigated the effects of the introduction of real-time information on people's waiting time perception changes over time, using surveys one month before, and three months and 16 months after the system implementation. However, their study suffered from a limited study sample size.

2.4.4 Section Summary

To summarize, several studies investigated how users value their time during a transit trip and indicated that the relative value of waiting and travel times varies with income, location, trip distance and purpose, and survey method. Nevertheless, it is infrequent to find empirical studies that investigate the value of time savings and their reliability for transit users. It is common to find studies investigating passengers' waiting time perception, however, no study explicitly focused on understanding the impacts of bus delay or arrival variation on transit users' waiting time perception. Finally, although, several studies indicate a positive impact of service improvement strategies on user's perception after the immediate implementation of a new strategy, it is rare to find studies that investigate why exactly these strategies impact perception and how these perceptions change over time.

Table 2.2: Summary of studies on passengers' perspectives included in review

Study	Issues Addressed	Data source (s)	Sample size	Analysis methods	Measures Used	Key findings
Passenger time value						
Mohring et al. (1987), Singapore	Wage, and waiting and travel time values	on-board survey	11,438	Maximum likelihood estimates	• Travel time • Waiting time	• The value associated with time is usually higher than the fare • The value associated with in vehicle time is around half the equivalent of an hourly wage, waiting time is valued at 2-3 times that of in-vehicle time
Leclerc et al. (1995), New York, USA	Risk behaviour, money and time value	8 surveys	756	Descriptive statistics	• Waiting time	• The value of consumers' waiting time is not constant but depends on contextual characteristics of the decision situation • Respondents preferred risk-averse choices with respect to decisions in the domain of time
Wardman (2001), England	Time and service quality value	Meta-analysis using various data sources	143 studies	Regression models	• Walking time • Waiting time • Travel time	• Walking time, waiting time, and combined walking and waiting time are valued 1.66, 1.47, and 1.46 respectively times as much as in-vehicle time
Wardman (2004), England	Value of Walk time, waiting time	Meta-analysis using various data sources	171 studies	Regression models	• Walk time • Wait time • Headway • Travel time	• Waiting time is valued at 2.5 times as much as in-vehicle time, while walking time is valued at 2 times travel time • The value of headway depends upon journey purpose and distance
Nam et al. (2005), na	Importance of travel time reliability	On-site survey	Na	Multinomial and Nested Logit model	• Travel time	• The value of reliability is greater than values of travel time. Reliability was expressed in terms of standard deviation
Pinjari & Bhat (2006), Austin, USA	Value of Travel time and travel time variation	Web-based survey	317	Mixed logit model	• Travel time	• The values of travel time and travel time unreliability were found to be nonlinear • During the first 15 minutes of a trip, passengers place a small value on travel time while placing a higher value on travel time reliability. The value of travel time increases rapidly after the first 15 minutes while the valuation of reliability falls radically

Study	Issues Addressed	Data source (s)	Sample size	Analysis methods	Measures Used	Key findings
(Shires & de Jong, 2009)	Value of travel time savings	Meta-anlysis using various data sources	77 studies	Panel data models	• Travel time	• The value of travel time savings varies by income, country, travel purpose, mode, distance and by survey method
Politis et al. (2010), Thessaloniki, Greece	The value of real time Information System	On-site survey	300	Descriptive statistics	• Waiting time • Number of trips	• Users value real time information services at, on average, 24.0% of the current fare • Women value the service more than men • About 20 % of the overall sample stated that they have undertaken more trips as a consequence of the information system
Abrantes & Wardman (2011), England	The value of travel time	Meta-analysis using various academic and reports	226 studies	Regression models	• Travel time	• The ratio between walk and wait time and in-vehicle time was found to be lower than the commonly used value of two • There is a large and significant difference between the results from studies based on the type of suervey used
Passenger perceptions regarding time						
Strathman et al. (1999), Portland, USA	Automated Bus Dispatching impacts	On-board survey (rating 1-4 scale)	1815	Descriptive statistics	• Reliability • Satisfaction	• Users rated a frequent service as the most reliable and gave it the highest overall satisfaction rating, while it has the lowest reliability (in terms of the coffecient of variation of running time and headways)
Hall (2001), Los Angeles, USA	Perception of Waiting time	On-site survey & AVL data	1199	Regression models and logit models	• Waiting time	• Perceived waiting time varies according to age group, destination, primary language, as well as for first-time users. • People who knew the schedule were more inclined to believe the bus was late than those who did not know the schedule
Hess et al. (2004), Los Angeles, USA	Perception of Waiting time	On-site survey & manual headway data	281	Descriptive statistics	• Waiting time	• Riders overestimated their wait time by a factor of two when it was imposed by the transit system, but accurately estimated their wait time when they chose to wait for the free bus ride

Study	Issues Addressed	Data source (s)	Sample size	Analysis methods	Measures Used	Key findings
Hollander (2006), city of York, England	Travel time variability and trip time choice	Web-based survey	244	Multinomial logit	• Travel time variability	• The influence of travel time variability on bus users is best explained indirectly through scheduling considerations • The penalty placed on early arrival to the destination is found to be similar to the penalty on travel time itself; late arrivals are much more heavily penalized
Mishalani et al. (2006), Ohio, USA	Perception of waiting time	On-site survey	83	Regression models and descriptive statistics	• Waiting time	• Their results indicated an overestimation of waiting time by passengers compared to their actual waiting time at stops by 0.84 minutes
Daskalakis & Stathopoulos (2008), Athens, Greece	Perception of waiting time and headways	On-site survey	300	Mathematical models	• Waiting time	• The greater the headway, the greater the deviation the users perceive, but at a diminishing rate. • A reliable service, meaning smaller deviations, is more appreciated by the public than any service of shorter headways and less reliability
Fan & Machemehl (2009), Texas, USA	Waiting time and Arrival pattern	Observation & video recording	2237	Linear regressions	• Waiting time • Arrival pattern	• They identified a threshold of 11 minutes that passengers begin to coordinate their arrivals to the bus stops as predetermined as at schedules
Dell'Olio et al. (2010), Santander, Spain	How perception of quality varies according to the available information	Focus groups, on-board and on-site survey	768	Ordered probit models	• Waiting time • Travel time • Reliability	• The perception of quality is shown to change with the category of user (frequency of use, income, gender, age, car ownership) • Users tend to be more critical in terms of perception of Overall Quality until they are stimulated into thinking more deeply about other influential variables • As a general rule, the number improving their score is practically double the number reducing it for the same situations
Eboli & Mazzulla (2011), Italy	Asymmetric user perception	Survey (rating 1 to 10)	470	Mixed logit model	• Service quality	• Users' perceptions of transit services are heterogeneous: for many reasons: the qualitative nature of some service aspects, the different users' socioeconomic characteristics, the diversity in tastes and attitudes towards transit
Psarros et al.	Perception of	On-site survey	1000	Hazard-based duration	• Waiting time	• For all trip purposes – work, education, shopping and personal

Study	Issues Addressed	Data source (s)	Sample size	Analysis methods	Measures Used	Key findings
(2011), Athens, Greece	waiting time			models		affairs – there appears to be a strong positive effect on the length of perceived waiting time comapred to actual waiting time by 27%, 43%, 30% and 30%, respectively • Younger people estimate their waiting time more correctly than older people
Transit strategies impact* on passengers' perception						
Conlon et al. (2001), Chicago, USA	Express service	On-site survey (rating 1 to 5)	1,178, 1,006, and 730	Descriptive statistics	• Travel time • waiting time	• Customer satisfaction and loyalty measures, as measured by before-and-after customer satisfaction surveys, increased significantly for both local and express customers due the implementation of new express service
Dziekan & Vermeulen (2006), Hague, Netherlands	Real-time information displays impacts	Three mailed survey	53	Descriptive statistics	• Waiting time	• Passenger waiting time perception decreased after the implementation by 20% (1.30 minutes) without reporting any actual improvement in service, with no significant change in perception on the long term
Dziekan & Kottenhoff (2007), Stockholm, Sweden	Real-time information displays impacts	Several studies review	11 studies	Na	• Waiting time	• Only 4 studies report that users' perceived wait times were reduced due to the real-time information system implementation
Cain et al. (2010), Miami, USA	Reserved lanes impacts	Two on-board surveys (Rating 1 to 5)	572 and 349	Descriptive statistics and t-tests	• Travel time • OTP	• Express lanes, as measured by before-and-after surveys, have improved user perceptions of travel time and service reliability. • Travel time and rating increased by 0.23 points • Service reliability increased by 0.16 points • 63.9% perceived a 5- to 29-min, while the actual saving was 17 min
Barr et al. (2010), New york, USA	BRT system impacts	Na	Na	Na	• Travel time	• 89% said that BRT is better than the limited services, and 30% said that they were riding more frequently than before • 84% said that BRT is faster than the limited

Study	Issues Addressed	Data source (s)	Sample size	Analysis methods	Measures Used	Key findings
El-Geneidy & Surprenant-Legault (2010), Montreal, Canada	Express service impacts	On-site survey & AVL/APC data	340	Linear regressions and t-test	• Travel time	• Implementing a limited-stop service yielded 4.6 minutes savings (13% compared to the local service) in running time for the new limited service • Passengers tend to overestimate the savings associated with the implementation of the new limited-stop service by 4 to 7 minutes more than the actual savings
Yoh et al. (2011), California, USA	Relative importance of stop amenities on perception	On-site survey (Rating 1 to 4) and a value for waititng time	900	Regression models	• Waiting time	• Regardless of waiting time, safety and on-time performance were paramount to riders • Lighting, cleanliness, information, shelter, and the presence of guards were less important to travellers when waits were short, but were more important with longer wait times
Watkins et al. (2011), Seattle, USA	Real-time information via devices impacts	On-site survey	655 (13% are real-time users)	Linear regression models	• Waiting time	• Measured wait time, real-time information, PM peak period, bus frequency, and aggravation level impact users perception. • Real-time information users' perceived wait time = measured wait time. The addition of real-time information decreases the perceived wait time by 0.73 min
Diab & El-Geneidy (2012), Montreal, QC, Canada	A set of strategies impacts	AVL/APC & On-site survey	60,973	Linear regression models	• Travel time	• The combination of a set of strategies led to a 10.5% decline in running time along the limited stop service compared to the regular service. However, the regular route running time increased by 1% compared to the initial time period • Users tend to overestimate the savings associated with the implementation of this combination of strategies by 3.5–6.0 min and by 2.5–4.1 min for both the regular route and the limited stop service, respectively

2.5 TRANSIT AGENCY PERSPECTIVES

Across the U.S. and Canada, transit services are funded in part through public subsidies (American Public Transportation Association, 2011a). In addition, in each country, there is a national organization that tracks and supports public transit service, which requires transit agencies to file annual reports, to develop future plans, and to comply with various other requirements in order to receive federal funds (The Federal Transit Administration (FTA), 2012; Transport Canada, 2012). Therefore, and due to the spatial, political and financial context similarities, this study focuses solely on industry practice in North America. The following section discusses transit agencies' perspectives on reliability. The discussion provides insight into the following questions:

- How do transit agencies understand and realize reliability?
- How and to what extent do they measure riders' perceptions of service reliability?
- What reliability indicators do they use?
- What are their service improvement strategies?

A systematic evaluation method for transit agencies' plans was applied to identify each agency's definition of reliability, and reliability goals, objectives and strategies. A key word search for "reliability, "punctually", "transit", "bus", "perception", and "satisfaction" was performed to allocate the sections that needed to be reviewed. If agencies used words such as "mission", "goal" and "task", or employed key verbs, such as "define", "refer", or the verb 'to be' (e.g. reliability is….), the sentences' purpose were considered as a goal or as a definition, respectively. While if agencies used words such as "target", "objective", or contained key verbs, such as "aim', "intent", and "require", the sentences' purpose were considered as an objective. Then, the related paragraphs were checked to make sure that the used word was related to reliability and bus and/or transit service. If the agency indicated reliability as a main goal, the strategies used to improve the service were collected. For each transit agency, more than one report is included in the analysis to give more holistic ideas about its perspectives.

2.5.1 Transit Agencies' Understanding of Reliability

All the transit agencies included in this review indicate reliability as a priority. Most of them mentioned reliability in their broad mission statement or president's message as one of the most important strategic goals to be achieved. Among the examples, the chairman of NJ TRANSIT, New Jersey, stated that their mission is to "enhance reliability and safety" of transit services (NJ TRANSIT, 2012). In Chicago, the CTA president stated that his charge is to make sure that "(the service) is operating as reliably and efficiently as possible, … to strive to evolve and improve and to deliver on-time… service each and every day"(p.7) (Chicago Transit Authority (CTA), 2011). Similar examples of commitment to improve transit service reliability can be found across the reviewed transit agencies' plans.

Transit agencies define reliability in different ways. Among those who provided a definition of reliability, nearly all agencies define and operationalize reliability in term of measures, particularly those related to OTP. As an example, reliable service for TransLink, Vancouver, is regarded as "*designed to ensure OTP, avoiding being early & minimizing running late*" (p.3) (TransLink, 2004). WMATA, Washington, is "*dedicated to delivering service on time… to improve reliability*" (p.4) (WMATA, 2012). Other transit agencies including the King County Metro Transit, Seattle, defined it in terms of the overall availability of service. Regarding the objective of achieving reliability, around 80% of the reviewed transit agencies consider reliability as an objective in order to increase customer convenience, or as the measure that should be monitored in order to keep them satisfied and to improve ridership. For example, MTA in New York city, regards service reliability as the key factor to increase ridership (Metropolitan Transportation Authority (MTA), 2008). NJ TRANSIT (2011) stated that reliability is an important measure to *"meeting customers' needs."* OC-Transpo, Ottawa, stated that *"reliability is a key factor"* in building customer satisfaction (OC Transpo, 2012).

2.5.2 How Transit Agencies Measure Riders' Perceptions of Service Reliability

It is important to understand how transit operators view and recognize transit users' responses to service quality changes, particularly regarding their perspectives concerning reliability. Despite the fact that most of the reviewed transit agencies regard reliability as a key factor in building customer satisfaction, only 20% of transit agencies (3 out of 15) reported users' satisfaction about service reliability (or schedule adherence and OTP). For example, Miami-Dade Transit, Miami, indicated that the percentage of respondents satisfied with the reliability of bus service is 35% in 2008, while their target is 45%. The MTA indicated the passenger satisfaction level for their local buses' OTP reached 6.6 out of 10 in 2008 (Metropolitan Transportation Authority (MTA), 2008).

On the other hand, approximately 12% of the sampled agencies reported changes in the passenger complaint rate concerning reliability of service, including the MBTA in Massachusetts and Metrolinx in Toronto. Other transit agencies reported overall customer satisfaction of transit service along with other measures without reporting satisfaction with reliability. For example, the STM, Montreal, in their 2009 report, stated that "*the average level of customer satisfaction about all aspects of service is 86%"* (p.8). In addition, the STM in 2008 reported the level of overall customer satisfaction with transit (82%), the level of satisfaction with driver courtesy (81%) and safety (91%), without reporting reliability separately. It should be noted that a rating system (e.g. 1=Poor to 10=Excellent) was the major tool reported by transit agencies to indicate changes in passengers level of satisfaction.

2.5.3 Transit Agencies Reliability Indicators

Indicators are the quantitative measurement tools used to assess progress toward a desired outcome or objective (Maryland Department of Transportation, 2009a). Bates (1986), Benn (1995), and Kittelson & Associates et al., (2003) reviewed operators' performance measures. They report that OTP is the most commonly recognized and employed measurement used by transit operators in order to understand and achieve reliability. Along with previous research, this study indicates that most transit agencies define reliability in terms of OTP and are still using OTP-related measures. A few transit agencies use other measurements besides OTP, that relate to service interruption percentages, the percentage of delivered trips, or the mean distance between failures (MDBF). However, it is rare to find measurements related to headway and travel time variation (the importance of these measures will be discussed later). Only 20% of reviewed transit agencies (3 out of 15) used the percentage of big gap intervals and bunched intervals, headway adherence percentage and waiting time assessments as measures of reliability.

OTP is commonly expressed as the percentage of buses that depart or arrive at a given location within a predetermined range of time. The acceptable percentage threshold varies from one agency to another according to the target goal and the measured range of acceptable delay or earliness that an agency assumes would be acceptable for passengers to wait. For example, a transit agency can set a goal that requires 78% of their buses to be on time, using an acceptable range from 2 minutes early to 7 minutes late, like the WMATA. Another agency's goal can be the same (78%), using an acceptable range of from 1 minute early to 4 minutes late, such as in the case of SEPTA in Philadelphia. In addition, while the majority of transit agencies measure OTP as the bus arrival time at a number of points along the system, such as the last stop of some routes, the NJ TRANSIT measures OTP as the bus *departure time* within 1 minute early and 5 minutes late from a few time points along the system (i.e.

layover points mainly). On this basis, the NJ Transit achieved 94% in 2010 (NJ TRANSIT, 2010).

2.5.4 Agencies Strategies to Improve Service Reliability

Regarding the strategies that agencies use to enhance their service reliability, several are reported. These strategies are different from one transit agency to another according to the level of improvement required or provided by what has already been implemented (Hemily & King, 2008; Smith, Hemily, & Ivanovic, 2005). These strategies, by decreasing frequency of appearance order, are: transit signal priority (TSP), bus rapid transit (BRT) or BRT-like systems (rapid transit system or networks), new buses (low-floor buses and articulated buses), reserved bus lanes, limited-stop services (express buses), intelligent transportation system (ITS) and (AVL/APC) systems, and smart cards. Because BRT and BRT-like systems that combine more than one approach are more attractive than conventional transit routes operating with less speed and reliability, these systems are considered one of the most effective tools to increase service reliability, efficiency and ridership (Currie, 2006; The Canadian Urban Transit Association (CUTA), 2007). About 20% of transit agencies (3 out of 15) considered reviewing their bus stop location, route design and structure, and driver training.

2.5.5 Impact of Strategies on Service

A number of studies discussed the impacts of different improvement strategies on transit service. These studies are presented in Table 2.4. Most of the studies are done in response to the cooperation between transit agencies and researchers to understand the impacts of their actions on service. Thus, these studies are evaluational studies that use a before-and-after design to assess and provide evidence of the impacts of interventions. Other studies not included in the review generally focused on understanding the general factors impacting the service, such as distance, weather, time periods, number of passengers and land use (Mazloumi, Currie, & Rose, 2010; Patnaik, Chien, & Bladikas, 2004; Rajbhandari, Chien, & Daniel, 2003).

The majority of the study concentrated on running time improvements that resulted from implementing these strategies. Several studies agreed that limited-stop bus service and reserved bus lane decrease running time (El-Geneidy, Strathman, Kimpel, & Crout, 2006; El-Geneidy & Surprenant-Legault, 2010; Surprenant-Legault & El-Geneidy, 2011), while low-floor buses decrease dwell time (Dueker, Kimpel, Strathman, & Callas, 2004). Strathman et al. (2000) indicate buses' running times are significantly shorter due to the implementation of the dispatch system. The use of articulated buses along a transit corridor is expected to have a mixed effect on running time (El-Geneidy & Vijayakumar, 2011). It decreases running time due to the existence of the buses' third door, while also increasing it due to the longer acceleration and deceleration time. The use of the smart card increases running time compared to using the traditional flash passes (Diab & El-Geneidy, 2012), while it decreases the running time compared to magnetic strip tickets, but only when the bus is not crowded (Milkovits, 2008). Kimpel et al. (2005) indicate that the expected benefits of TSP are not consistent across routes and time periods.

Concerning the service variation, few studies indicated that driver experience and behaviour are important factors affecting transit service running time and its variability (Abkowitz et al., 1978; El-Geneidy et al., 2011; H. Levinson, 1991; Strathman & Hopper, 1993; Strathman et al., 2002). El-Geneidy et al. (2006) analyzed the impacts of bus stop consolidation on bus performance. They indicate that while bus running time improves due to implementation, this does not impact the service running time variation nor headway variation. Yetiskul and Senbil (2012) indicate that new buses decrease running time variation. Finally, Diab and El-Geneidy (2012; 2013) provided two detailed studies that explore the impact of a combination of service improvement strategies on service running time and its variation. They indicated that strategies may have unexpected impacts when they are implemented together. Therefore, understanding the synergies and the collective impacts of strategies is needed.

2.5.6 Section Summary

To summarize, transit agencies consider reliability to be a priority, defining it in terms of OTP measures to achieve the objective of increasing customer satisfaction. They do not frequently report users' satisfaction regarding service reliability despite its perceived importance. Additionally, the majority of transit agencies use OTP measures with differing standards. Finally, no transit agency indicated using only one improvement strategy; they often employ TSP and BRT or BRT-like systems that combine a few strategies in order to enhance the service. On the other hand, discussion of the impact of improvement strategies focused on understanding the effect of only one or two strategies on the service running time and dwell time. Only a few studies focused on exploring the joint impact of a set of strategies on the service quality.

Table 2.3: Summary of transit agencies plans included in review

Agency	Reliability definition/goal	Objective or expected benefits	Performance measures*	Strategies and policies	Users Perception	Reference
South Coast British Columbia Transportation Authority (TransLink), Vancouver, Canada	• Improve OTP • Avoid being early • Minimize running late	• Increase customer satisfaction	• OTP (0 min +3 min) • Delivered trips (%) of scheduled trips	• Transit priority system (TSP, bus lanes, queue jumpers) • Express service • Bus bays improvements • Articulated buses	• Overall satisfaction ratings (e.g. 7.3 out of 10 in 2009)	(TransLink, 2004, 2009, 2012)
Toronto Transit Commission (TTC), Toronto Canada	• Increase OTP and decrease cancellations	• Compete effectively with the automobile	• OTP • Monitored monthly	• BRT • Rapid Transit Network • TSP, Bypass, Shoulders ITS	• Less complaints about reliability every three months • Customer satisfaction rating	(Metrolinx, 2008; Toronto Transit Commission (TTC), 2009, 2013)
Société de transport de Montréal (STM), Montréal, Canada	• Increase bus punctuality	• Improve customer experience	• OTP (-1min +3 min) • Target: 83%, (82.6 in 2008 and 83.6% in 2009)	• TSP and ITS • Express service • Reserved bus lanes • Street layout	• Overall customer satisfaction (81% in 2008 and 86% in 2009)	(Société de transport de Montréal, 2009, 2010, 2011b)
OC Transpo, Ottawa, Canada	• Achieve scheduled service availability • OTP		• OTP (0 min +5 min) at time points • Cancelled trips (%) of scheduled trips • Average transit vehicle speed	• Rapid transit system • TSP • Road geometry changes • Reserved lanes • Queue jumps	• Using customer satisfaction surveys	(OC Transpo, 2009, 2012; The City of Ottawa, 2008)
Metropolitan Transportation Authority (MTA), New York, USA	• Improve performance	• Ridership	• Mean Distance Between Failures (MDBF) • Bus wait assessment percentage for high-volume bus lines and limited stop service	• Express service • New Buses • TSP • BRT (off-board fare collection, TSP, Real time bus information) • New Fare collection system • Managing fleet defects • Improved schedules	• Ridership • Customer satisfaction rating (1 to 10) For OTP, Safety, and Overall	(Metropolitan Transportation Authority (MTA), 2008, 2009, 2011)

Agency	Reliability definition/goal	Objective or expected benefits	Performance measures*	Strategies and policies	Users Perception	Reference
San Francisco Municipal Transportation Agency (SFMTA), San Francisco, USA	• Meets core operational agency performance objectives (e.g. achieve OTP)	• Ability to speed transit • Meet Transit Effectiveness Project (TEP) objectives	• OTP (-1 min +4 min) • Headway adherence (as a secondary measure)	• BRT • Reserved bus lanes • All-door boarding • Stop spacing • TSP and signal timing • Articulated buses • Improving fare collection system	• Using customer satisfaction surveys	(San Francisco Municipal Transportation Agency (SFMTA), 2011, 2013; SFMTA & Nelson\Nygaard Consulting Associates, 2008)
Chicago Transit Authority (CTA), Chicago, USA	• Minimize system delays manage rail and bus intervals	• Decrease delay and bus bunching	• Percentage of Big Gap Intervals • Percentage of Bunched Intervals	• BRT • TSP • Articulated buses. • Bus arrival information	• Number of complaints	(Chicago Transit Authority (CTA), 2011, 2013)
Maryland Transit Administration (MTA), Maryland, USA	• Quality of service/ efficiency • OTP	• Ridership	• OTP • Target: 90% (87% in 2010)	• AVL system and centralized control center • CharmCard smart card • Express service • Fleet replacements	• Using customer satisfaction rating (1 to 5)	(Maryland Department of Transportation, 2009b, 2011)

Massachusetts Bay Transportation Authority (MBTA), Boston, USA	• Service should be operated as scheduled	• Decrease unpredictable wait and/or travel times.	• OTP
			  • Headways ≥10 min: OTP at start (0 min +3 min), mid (0 min +7 min), and at end (-3 min +7 min)
			  • Headways <10 min: OTP within 1.5 times of scheduled headway, and OTP at end within 20% of run time
				• BRT
				• AVL/APC
				• Newer buses (Low-floor buses)
					• Rider complaints
					• Public meetings feedback
						(Massachusetts Bay Transportation Authority (MBTA), 2008, 2009; MassDOT, 2013)

Agency	Reliability definition/goal	Objective or expected benefits	Performance measures*	Strategies and policies	Users Perception	Reference

Southeastern Pennsylvania Transportation Authority (SEPTA), Philadelphia, USA	• Improve OTP		• OTP (-59 sec +4min)
			  • Bus arrival
			  • Target 78% in 2011 (75% in 2010)
			• MDBF: target 9125 in 2012 (7,066 in 2010)
			• Report every 6 months
				• New Technologies
				• New payment methods
				• Evaluate schedules
				• Route adjustments
					• Reliability for all modes (7.8 in 2012 out of 10)
					• Using customer satisfaction rating (1 to 10)
						(Southeastern Pennsylvania Transportation Authority (SEPTA), 2010, 2011, 2013)

NJ TRANSIT, New Jersey, USA	• Achieve OTP	• Decrease delays	• OTP (-59 sec +5min)
			  • Bus departure at few main stations
			  • 94% in 2010 (No target)
				• Newer full-size buses
				• Low-floor buses
				• “Tap & Go” system
					• Using customer satisfaction rating (1 to 10)	(NJ TRANSIT, 2010, 2012)

Washington Metropolitan Area Transit Authority (WMATA), Washington, D.C. USA	• OTP	• Meet customer expectations by consistently delivering quality service	• OTP (-2 min +7 min)
			  • Arrival time at a time point
			  • Target 78% in 2013 (77.5% in 2012)
			• MDBF: Target 8100 miles in 2013 (8485 miles in 2012)
			• Reported quarterly
				• Priority Corridor Network (TSP and exclusive bus lanes)
				• Management actions
				• Express service
				• Route adjustments
					• Reliability (73% in 2012)
					• Overall customer satisfaction (81% in 2013)
						(WMATA, 2010, 2012, 2013)

King County Metro Transit – Department of Transportation, Seattle, USA	• Decrease late trips	• Improve satisfaction	• OTP (-1 min +5 min)
			  • Target 80% in 2013 (77.5% in 2012)
			  • PM Peak period 65 %
			  • Reported monthly
			  • Measured at time points
				• Rapid transit
				• Schedule revisions
				• TSP
				• Bus reserved lanes
				• Queue bypass
				• Stop consolidation
					• Customer Satisfaction of OTP
					• Customer complaints
						(King County Metro Transit, 2007, 2013a, 2013b)

Agency	Reliability definition/goal	Objective or expected benefits	Performance measures*	Strategies and policies	Users Perception	Reference
Denver Regional Transportation District (RTD), Denver, USA	• On-time as scheduled service	• Decrease users' waiting time • Ridership • Riders deserve on-time service	• OTP (-1 min +5 min) • Max 30 minutes delay	• TSP • Bus lanes • BRT		(City of Denver, 2008; RTD, 2011, 2012)
Miami-Dade Transit, Miami, USA	• Improve OTP	• improve riders satisfaction	• OTP (-2 min +5 min) • Target 80% (79% in 2009 and 80% in 2012)	• TSP	• % of users satisfied with the service reliability (35% in 2008, target 45%)	(Miami-Dade Transit, 2009, 2012a, 2012b)

***OTP**: on-time performance; **MDBF:** mean distance between failures; **Big Gap interval:** An instance when the time in between buses is more than double the scheduled interval, or a gap of more than 15 minutes; **The percentage of bunched intervals:** The number of bus intervals (time between two buses at a bus stop) that are 60 seconds or less divided by the total number of weekday bus intervals traveled during the month; **Bus wait assessment:** The percent of actual intervals between vehicles that are no more than the scheduled interval plus 25% of the headway.

Table 2.4: Summary of studies on service improvement strategies included in review

Study	Issues addressed	Data source (s)	Sample size	Analysis methods	Measures used	Key findings
Strathman et al. (2000) Portland, USA	Bus dispatching system (BDS) impact	Manual and AVL/ APC	830	Linear regression models	• Running time	• The implementation of bus dispatching system (BDS) decreased running time by 1.45 minutes (around 3% of the running time before BDS)
Strathman et al. (2002) Portland, USA	Drivers experience impact	AVL/ APC	110,743	Linear regression models	• Running time	• Bus operators are an important source of running time variation after controlling for such factors as route design, time of day and direction of service, and passenger activity • Operators' relative running time decreases by 0.57 seconds for each month of additional experience
Dueker et al. (2004), Portland, USA	Low-floor buses impact	AVL/ APC	353,552, 2,347, 16,504, 18,098	Linear regression models	• Dwell time	• The dwell time model for the without lift operation sub-sample yields an estimated effect of a low-floor bus of -0.11 seconds (-0.93%) per dwell • A low-floor bus reduces dwell time for lift operations by nearly 5 seconds (-4.74 or 5.8 %)
Kimpel et al. (2005), Portland, USA	Transit signal priority (TSP) impact	AVL/APC	18,132	Summary stats & and a regression model	• Running time	• The study shows that the expected benefits of TSP are not consistent across routes and time periods, nor are they consistent across the various performance measures (e.g. running time, running time variation, headway and OTP)
El-Geneidy et al. (2006), Portland, USA	Stop consolidation impact	AVL/APC	332	Linear regression models	• Running time • Running time variation	• The results indicate that bus stop consolidation had no significant effects on passenger activity, whereas bus running times improved by nearly 6%. Running time improvements may have been limited by insufficient schedule adjustments. No evidence was found about the impact of stop consolidation on running time variation or headway variation
Milkovits (2008), Chicago USA	Smart cards and bus type impact	AFC/AVL/ APC	165,000	Linear regression models	• Dwell time	• Smart cards are estimated to have a 1.5-s faster transaction time than magnetic strip tickets, but only in uncrowded situations. When the number of onboard passengers exceeds the seating capacity, there is no statistically significant difference between the fare media types

Study	Issues addressed	Data source (s)	Sample size	Analysis methods	Measures used	Key findings
El-Geneidy et al. (2011), Minneapolis, MN, USA	Drivers Experience impact	AVL/APC	21,275, and 97	linear regression models	• Running time • Running time variation	• Drivers' experience decrease run time by 0.34 for each additional year of experience • A 1% variation in drivers' experience leads to 5% decline in the run time coefficient of variation
Surprenant-Legault & El-Geneidy (2011), Montreal, Canada	Reserved lanes impact	AVL/APC	4,384	Linear regression and logit models	• Running time • OTP	• The reserved bus lane yielded savings of 1.3% to 2.2% in total running time, and benefits were more significant for northbound afternoon peak trips than for southbound morning peak trips because of congestion levels northbound • The introduction of a reserved lane increased the odds of being on time by 65% for both routes
El-Geneidy & Vijayakumar (2011), Montreal, QC, Canada	Articulated buses impact	AVL/APC	253,260 and 9,235	linear regression models	• Running time • Dwell time	• Operation of articulated buses yielded savings in dwell time, especially with high levels of passenger activity and the use of the third door in alighting • However, these savings were not reflected in running time, since articulated buses are generally slower than regular buses
Yetiskul & Senbil (2012), Ankara, Turkey	New buses in the fleet impact	AFC data	3,150, 2,481 and 7,424	linear regression models	• Running time variation	• Three main causes of travel-time variability have been identified and tested in this study: temporal dimension, spatial dimension, and service characteristics • Model results indicate that all of these factors affect travel-time variability
Diab & El-Geneidy (2013), Montreal, QC, Canada	A set of strategies impact	AVL/APC	255,000 and 447	linear regression models	• Running time variation • Running time deviation variation	• The introduction of a smart card fare collection system increased bus running time and service variation compared to the initial situation. • Articulated buses, limited-stop bus service and reserved bus lanes have mixed effects on variation in comparison to the running time changes, while TSP did not show an impact on variations

2.6 DISCUSSION AND CONCLUSIONS

The main objective of this chapter is to address simultaneously, within the scope of reliability, passengers' and transit agencies' perspectives. Figure 2.1 illustrates the research structure and the key findings. The shaded area within the arrows shows the overlap in the understanding and linkage areas. The area outside the arrows presents the disconnect area, which signifies the important gaps and mismatches in the understanding of reliability. The factors in this area need to be integrated and addressed to enable transit agencies to achieve better service that is positively perceived by passengers. The following section discusses this chapter’s key findings in detail.

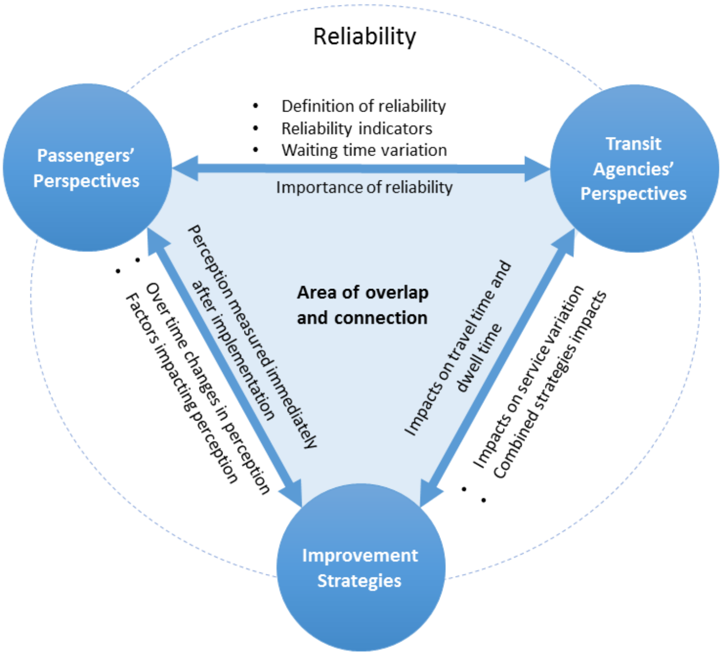


Figure 2.1: Research structure and main findings

2.6.1 Passengers’ and Agencies’ Perspectives

The overlap between passengers’ and transit agencies’ perspectives on reliability centres on agreement about its importance to the service provided. The key differences between both perspectives are related to the definition of reliability, to the standard viewpoint regarding OTP, and to the unaddressed waiting time variation.

Passengers think about reliability in terms of consistently minimizing their overall waiting time and travelling time. They consider waiting and running times and their variation as reliability measures since they affect their decision of departure time (Hollander, 2006) and daily activity planning (Leclerc et al., 1995). In contrast, operators mainly define reliability in terms of on-time performance (OTP) standards (or adherence to schedules). From a passenger's perspective, there are few drawbacks related to an OTP standard because it only introduces a number or percentage of vehicles located within a fixed tolerance based on the schedule. OTP does not take into account the amount or severity of delay or the bandwidth of arrival deviation from schedules (Camus et al., 2005). Therefore, it does not provide much information about the changes that occur in passengers' waiting times. It should be noted that some transit agencies not included in this chapter, such as Transport for London, London, UK, uses passengers' excess waiting time (EWT) to measure the additional waiting time for passengers over and above that which would be expected if all services ran on time.

In addition, particular attention must be given to the main aspect of passengers' views relating to the reliability of transit service: their response to waiting time variation due to bus delays. In fact, capturing and isolating waiting time variations experienced by users due to late buses are difficult. Researchers simply cannot know when users' actual waiting time starts in correlation with how much longer they waited behind the schedules (for the late buses). This is because researchers have to interrupt users to ask them about their perception, which is not capturing the full impact of delays on perception. Therefore, in the literature, it is still unclear how people perceive wait time variation and how they act during that experience. Thus, transit planners should support the concept that measurement of service variation can fundamentally address the quality of service, which can then decrease service variations and, consequently, users' waiting time variations. Variation can be expressed using various measures including headway variation and travel time variation. These measures are more relevant to a passenger's experiences of daily changes and delays than a discrete on-time window that may be practical for evaluating the reliability of the system's operational plan from a transit agency's perspective.

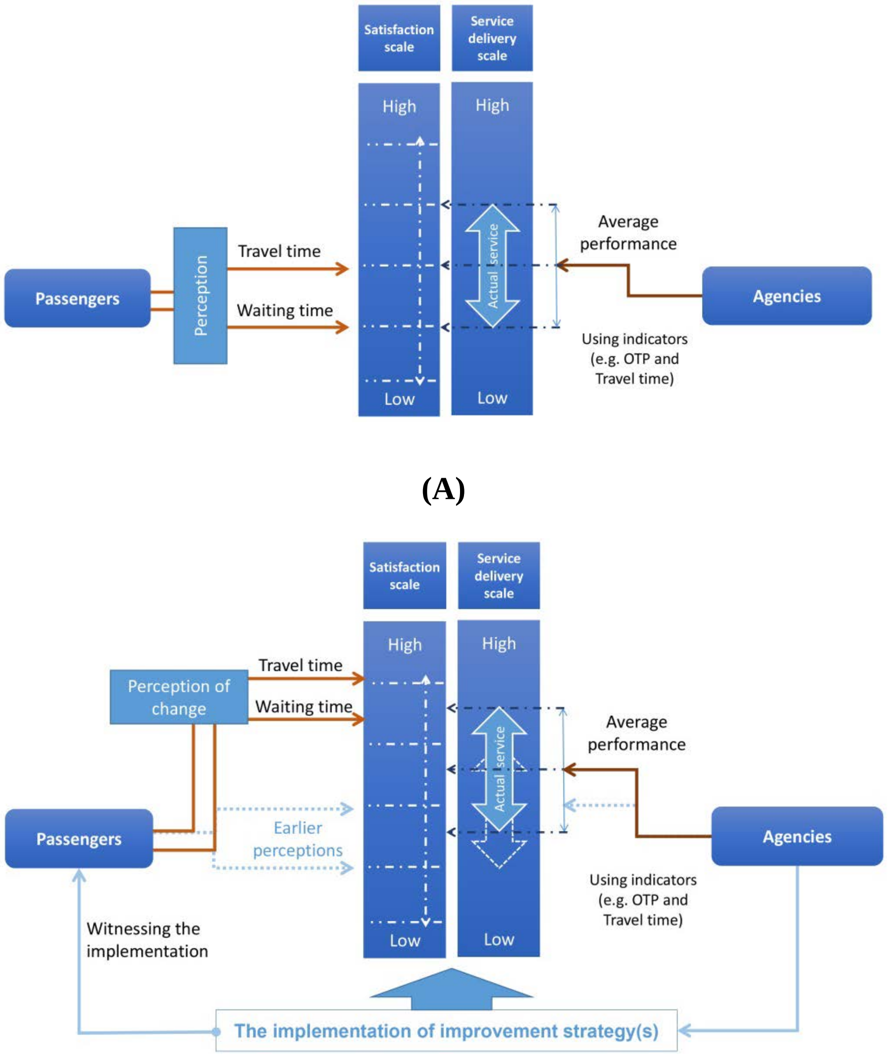
Accordingly, given the classic dilemma of valuing passenger time, transit agencies should account for passengers' waiting time more carefully by determining and addressing the difference between *expected* waiting time values for passengers and the *added* waiting time imposed by operators due to delays. Waiting imposed by operators makes passengers spend time stressed because they experience anxiety related to the fear of not meeting their target arrival time at their destination. Therefore, the value of waiting time can reach as much as 12 times the value of in-vehicle time and it changes according to users' preferences, time planning and their situations, as stated earlier (Iseki, Taylor, & Miller, 2006; Reed, 1995).

The majority of transit agencies indicate using passengers' surveys to measure users' perception. Nevertheless, these surveys should not only be utilized to track changes in service quality but also to help prioritize future improvements for service quality initiatives and strategies. Rather than using a satisfaction rating system, these surveys should consistently require users to quantify their waiting time and travel time (and their changes). This would give a better connection between passengers' perceptions and improvement efforts made by agencies, which may lead to more accurate integration between users' perceptions and policy making during the service planning and operation process.

2.6.2 Passenger Perspective Relative to Service Improvement Strategies

A number of studies examined the immediate impact of the implementation of different strategies on users' perceptions, and they generally indicate that passengers tend to perceive the service more positively after the implementation of a new strategy (Cain et al., 2010; Conlon et al., 2001; Currie, 2006; El-Geneidy & Surprenant-Legault, 2010). Figure 2.2-A shows a conceptual framework of how transit agencies measure their performance, and the nature of the passengers' perception of the *regular* or *standard* service attributes. It shows that while agencies measure and capture the actual average service, passengers perceive it differently, particularly concerning their waiting time (Kittelson & Associates, KFH Group, et al., 2003). The main conflict is related to passengers' perception when the agency implements strategies in order to improve the service. Figure 2.2-B shows this conceptual framework related to when transit agencies implement an improvement strategy. In this case, transit users tend to be satisfied and significantly overestimate their benefits (ICF Macro, 2011). This bias may occur because users are witnessing the implementation of such measures, as well as the related time cost saving that they experience. However, the question of why 'exactly' users overestimate these benefits is not presented in the literature. In addition, it is rarely discussed how these positive estimated perceptions can change over time (shifting back from Figure 2.2-B to Figure 2.2-A).

Unfortunately this tendency to be satisfied is yet to be successfully quantified and put to use, and will remain that way as long as transit agencies and researchers are capturing passengers' satisfaction and perception using mainly customer satisfaction rating techniques. The traditional rating techniques' results are devoid of specific insight into how people are overestimating and quantifying their time changes according to changes in service quality. In fact, the availability, affordability and accuracy of AVL/APC systems data offer a good opportunity to understand and present better estimations of how passengers estimate and perceive actual time changes in relation to implemented strategies. This is an important policy-relevant issue, since agencies should understand the quantitative effects of their policy and implemented strategies not only on their performance, but also on passengers' perception. Such knowledge will provide an understanding of the link between passengers' perception and the benefits of using a specific strategy, which may lead to more accurate measures and predictors of behavioural responses and, as a result, improved cost-benefit evaluations of transportation projects.



(A)

(B)

Figure 2.2: (A) Perception of regular service; and (B) Perception after the implementation of improvement strategies.

2.6.3 Transit Agencies Perspective Relative to Service Improvement Strategies

It is essential to assess to what extent the academic literature provides transit agencies with useful information related to the impact of various strategies. The impacts of various strategies on run time and dwell time have long been discussed in the literature. However, it appears that less attention has been given to the impact of various strategies on service variation. Furthermore, it is rare to find studies that provide a comprehensive analysis of the impacts of implementing a set of strategies on service reliability as well as passengers' perception of these changes. These are important issues since strategies may have unexpected impacts when they are implemented together. Therefore, understanding the synergies and the collective impacts of these strategies is needed (Diab & El-Geneidy, 2012, 2013). This is particularly relevant to transit agencies' practice, since no transit agencies indicated using only one strategy to improve their service, and they often employ BRT or BRT-like systems (that combine a few strategies in order to improve the service).

This knowledge is important to help transit agencies prioritize one strategy or a set of strategies over the others. The current literature's limited focus on transit agencies' knowledge needs may be limiting the latter's ability to correctly anticipate the impacts of their efforts on the service, and accordingly, on passengers' perception. Therefore, it is suggested that researchers should provide more in-depth studies regarding the comprehensive impacts of improvement strategies while understanding how these may function together to affect the transit performance and its variation. This level of complexity can be investigated using different automatic data collection systems, thereby giving transit agencies a better idea about the impacts of efforts on service and on passengers. Finally, while this research has focused on the North American experience regarding transit agencies' perspective, lessons can be learned and applied across other areas of the world, enabling transit agencies to achieve better service reliability that is positively perceived by the public.

3 CHAPTER THREE: UNDERSTANDING THE IMPACTS OF A COMBINATION OF SERVICE IMPROVEMENT STRATEGIES ON BUS RUNNING TIME AND PASSENGER’S PERCEPTION

3.1 OVERVIEW OF CHAPTER

Transit agencies implement many strategies in order to provide an attractive transportation service. In this chapter, I aim to clarify the collective impact of a combination of measures on the running time of transit services and passengers' perception, while investigating the synergies between strategies. Synergies between strategies are an important aspect of the service that may have an impact on the overall quality of service offered. As indicated in Chapter 2, the majority of the literature covering the improvement strategies of transit agencies relates to investigating the effects of one or two strategies meant to improve a service. However, transit agencies often combine multiple strategies, as in the case of boulevard Saint-Michel. In an attempt to improve transit service along the bus corridor, the STM has implemented a series of measures. These measures include using smart card fare collection, introducing limited-stop bus service, adopting reserved bus lanes, using articulated buses, and implementing transit signal priority (TSP). This chapter makes use of stop-level data collected from the STM’s automatic vehicle location (AVL) and automatic passenger count (APC) systems as well as a passenger survey done in June 2011. The combination of strategies used has led to a 10.5% decline in running time along the limited stop service compared to the regular service. The regular route running time has increased by 1% on average compared to the initial time period. The chapter also shows that riders are generally satisfied with the service improvements. They tend to overestimate the savings associated with the implementation of this combination of strategies by 3.5–6.0 min and by 2.5–4.1 min for both the regular route and the limited stop service, respectively.

The chapter presents original information, assessing the impact of a combination of measures on bus running time, while showing how these measures may function together, which is completely absent from the existing literature. The second purpose of this chapter is to understand the impact of the STM's implemented strategies on passenger's perception, by comparing perceptions to the actual changes in service along the bus corridor. This link between the quantitative measures of service and the perceived value provide us with valuable information that shows to what extent they overestimate their travel time benefits.

3.2 INTRODUCTION

Boulevard Saint-Michel is a heavily used bus corridor located to the east of Montréal's central business district, in the province of Québec, Canada. According to official estimates this corridor serves around 43,000 passengers per day. The service is operated by the Société de Transport de Montréal (STM), the transit provider on the island of Montréal, and moves more than 1.2 million riders per weekday on its 4 metro lines and 202 bus routes. In an attempt to improve transit service on the island, STM has implemented a series of measures. These measures include implementation of a smart card system called 'OPUS' in April, 2008, to provide passengers with the attractive advantages of automated fare collection (Société de transport de Montréal, 2010). At the same time, the STM made the decision to activate a limited-stop bus service (Route 467) running parallel to the regular bus service (Route 67) along the Boulevard Saint-Michel corridor. On March 30th, 2009, the STM implemented this new service. The new route serves only 40% of the stops along Route 67, with an average stop spacing of 615 metres. Route 467 runs on weekdays from 6:00 A.M. to 7:00 P.M., with an average headway of 10 minutes and 7 minutes during peak hours. Starting on August 3rd, 2009, the STM began to operate a reserved bus lane during peak hours in order to improve the service. On February 1st, 2010, the STM continued its series of improvements along the corridor by assigning a number of articulated buses to serve Route 467. Finally, on September 1st, 2010, the STM equipped a few of these buses with transit signal priority (TSP) systems which operate across all signalized intersections along the corridor. Figure 3.1 is a timeline showing the modifications applied to the routes analyzed between January 2007 and April 2011.

This chapter aims to evaluate the impact of this combination of measures implemented by STM on bus running time and passengers' perception of these changes in service. This is done through analysing archived AVL/ APC data for Routes 67 and 467 and conducting on-site surveys to gauge the perceptions of passengers using these two routes. The chapter starts with a literature review of bus running time, limited-stop service, smart card use, exclusive bus ways, articulated buses, and TSP systems. This is followed by a description of the studied route. The next section pertains to the methodology used to prepare and analyze the data for running time and survey questions. This is followed by a discussion of those results, and wraps up with a reiteration of the main conclusions.

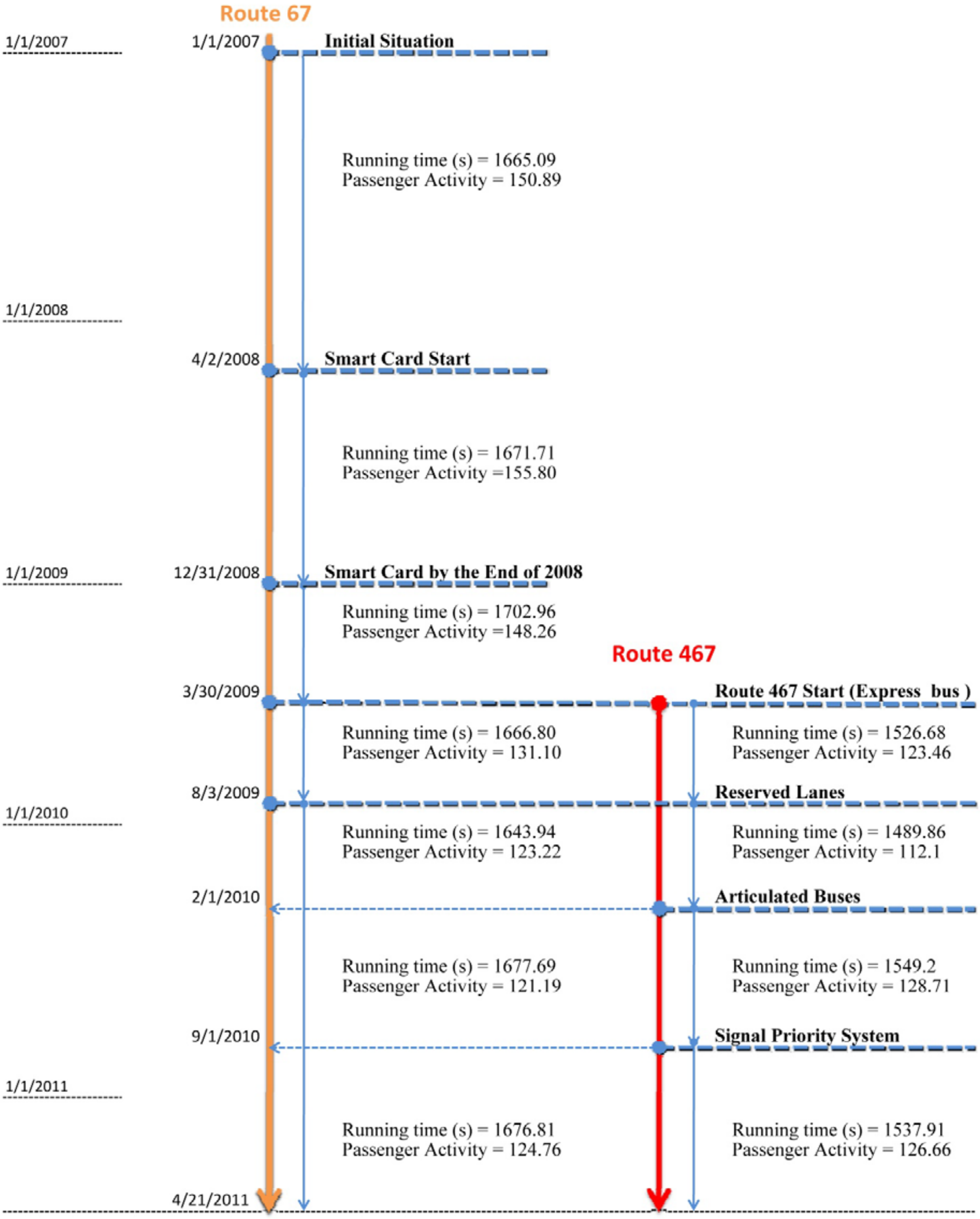


Figure 3.1: Time line of changes in bus service along Route Saint Michel

3.3 LITERATURE REVIEW

Transit users consider a service reliable when their in-vehicle time (i.e. running time), access and egress time (Hensher, Stopher, & Bullock, 2003; Murray & Wu, 2003), and their waiting time at stops are all minimized. Reduction in running time is expected to increase ridership and rider satisfaction (Hensher et al., 2003). Running time is the time that it takes a bus to move between two defined points during a trip along a specific route. A review of previous studies in transit literature identified several common factors that influence running time. These factors include passenger activity, load, distance, delay at the beginning of a trip, period of the day, number of actual stops made, weather and traffic conditions (Abkowitz & Engelstein, 1983; H. Levinson, 1983; Strathman et al., 2000). Transit agencies generally try to reduce the effect of these factors and enhance the quality of service by adopting different strategies. These strategies are determined according to the project location, funding and required improvements. Strategies may include smart card fare collection systems, reserved bus lanes, limited bus stop service, articulated buses, and TSP systems. Nevertheless, a direct method to evaluate the success of these strategies is to generate running time models, using before and after data while isolating the impact of each strategy through the use of dummy variables. Synergies can also be measured through a single dummy variable comparing the before to the after time period. Running time models that use archived AVL/APC data are well known in the transit literature, and have been adopted by several researchers (El-Geneidy et al., 2006; Kimpel, 2001; Kimpel et al., 2005). To a great extent, the majority of literature covering transit agencies improvement strategies has been done by investigating the effects of one or two strategies meant to improve the service. Several studies concurred that limited-stop bus service, reserved bus lane, and TSP decrease running time (Kimpel et al., 2005; Surprenant-Legault & El-Geneidy, 2011; Tétreault & El-Geneidy, 2010), while articulated buses and smart card systems increase running time (El-Geneidy & Surprenant-

Legault, 2010; El-Geneidy & Vijayakumar, 2011; Surprenant-Legault & El-Geneidy, 2011). While the following section will review the literature covering these strategies and their expected impact, none of these studies provide a comprehensive analysis to determine the impact of implementing this set of measures on bus running time for two parallel high-frequency routes (less than 10 minutes) sharing the same corridor.

Limited stop (express) service is considered one of the most effective strategies for decreasing running time (Ercolano, 1984; Furth & Day, 1985). Limited stop buses make only a few stops along a route, while a parallel regular route serves all stops, including the limited and intermediate stops. A few studies have been published estimating or reporting the savings resulting from the implementation of this service (Diaz & Hinebaugh, 2009; El-Geneidy & Surprenant-Legault, 2010; Tétreault & El-Geneidy, 2010). These savings vary depending on the number of stops included in the express service as well as the demand for this new service. As well, a limited number of studies concentrate on rider satisfaction and perception of time savings after the implementation of a service (Conlon et al., 2001; Furth & Day, 1985). The majority of research investigating the effects of reserved bus lanes on running time used simulation or has been derived from descriptive statistics (Shalaby, 1999; Tanaboriboon & Toonim, 1983; Thamizh Arasan & Vedagiri, 2010). One recent study provides more accurate estimates using before and after AVL/APC data to isolate the effect of a reserved lane. This particular study estimated that the time savings due to the implementation of a reserved lane ranged between 1.2 % and 2.3% of total running time (Surprenant-Legault & El-Geneidy, 2011). Moreover, smart cards can be used by transit operators to minimize fare fraud and pilfering (Corinne, 2008), to reduce operating and maintenance costs associated with magnetic strip card readers (Attoh-Okine & Shen, 1995), and to increase passenger satisfaction (Multisystems, Mundle and Associates, & Simon &Simon Research and Associates, 2003; Société de transport de Montréal, 2009). The most common smart card used in public transit is the contactless card, which is equipped with a microprocessor and operated by a reader through a radio frequency (Holcombe, 2005; Multisystems et al., 2003). According to previous research, the use of smart cards have had a general negative effect by increasing running time compared to the use of flash passes (El-Geneidy & Surprenant-Legault, 2010; Kittelson & Associates, KFH Group, et al., 2003; Surprenant-Legault & El-Geneidy, 2011).

Articulated buses can be found on heavily used routes (Jarzab, Lightbody, & Maeda, 2002; H. Levinson, Zimmerman, & Clinger, 2002) as they can carry more passengers than regular buses during one trip and have higher loading (boarding and alighting passengers) speeds (Kaneko, Iiuzuka, & Kageyama, 2006). Nevertheless, many transit agencies found that the maintenance cost and fuel consumption of articulated buses was higher compared to regular buses, while acceleration and performance were much lower (Hemily & King, 2008). The use of articulated buses along a transit corridor is expected to have mixed effects on running time. The first result is a negative effect which increases running time due to the acceleration, deceleration and manoeuvring time. The second consequence is a positive effect which decreases running time due to the decline in the time associated with passenger activity (El-Geneidy & Vijayakumar, 2011). In addition, TSP is a complex element, which involves traffic signal systems, transit vehicle detection systems and communication technologies. Evaluation of TSP is often done using simulation techniques as well (Balke, Dudek, & Urbanik, 2000; Dion, Rakha, & Zhang, 2004; Shalaby, Abdulhai, & Lee, 2003; Smith et al., 2005). Although the majority of TSP studies show improvements in running time, service reliability and efficiency, actual practice shows that significant differences are the exception rather than the rule (King County Department of Transportation, 2002). This is confirmed by a study developed in 2005 using archived AVL/APC data collected before and after TSP implementation (Kimpel et al., 2005). The study confirmed that TSP benefits are not consistent across routes and time periods.

3.4 METHODOLOGY

The data used in this study comes from STM's archived AVL/APC systems. The archived AVL/APC data is widely recognized in transit research as a rich source of information for planning and operational improvements (Dueker et al., 2004; El-Geneidy et al., 2006). However, only 18% of STM's buses (306 out of 1680) are outfitted with AVL/APC. STM assigns these buses to different routes in order to obtain a sample of network operational information. The data obtained for Routes 67 and 467 comprised a sample of 62,000 trip level observations (around 2,270,000 stop-level observations) for both routes. The data was collected between January 1st, 2007 and April 21st, 2011. This trip level data were cleaned by removing incomplete trips, holidays, weekend trips, system recording errors, trips with insufficient passenger activity (less than 6 boarding or alighting passengers), and trips during construction periods, altogether disqualifying around 1027 trips. After this data cleaning process, two datasets were constructed. The first include records from January to April 2007 and 2011, which contains 6,478 trips. The second dataset contains 60,973 complete trips between January 1st, 2007 and April 21st, 2011.

Figure 3.2 shows Route 467 and 67 as well as the analyzed segment along the routes. They run north-south (about 9.4 km, 5.8 mile) from boulevard Henri-Bourassa in the north to Rue Hochelaga in the south along boulevard Saint-Michel, crossing through five boroughs of the city of Montréal. Both Routes 67 and 467 share the same space and connect two metro stations, Joliette, at the end of the southbound line, and Saint-Michel station, at its midway point. The route's main corridor (boulevard Saint-Michel) consists of three lanes in each direction with no median island for the majority of the corridor. Route 67 average stop spacing is 241 and 255 metres in the southbound and northbound direction, respectively, while Route 467 is 611 and 623 metres in the southbound and northbound direction, respectively. As seen in Figure 3.2, the segment analyzed in this chapter stretches between boulevard Saint-Joseph in the south and rue Fleury in the north (6.82 km; 4.24 mile). This segment was chosen primarily because it did not experience any changes in terms of number of assigned stops or locations along boulevard Saint-Michel during the study period (2007-2011). A total of 28 signalized intersections function along the analyzed segment. All traffic signals are equipped with TSP functionality. The TSP system operates when a bus that is equipped with this technology is detected by the traffic signal while approaching an intersection. In that event either the green light is extended or a priority is activated, giving the bus a head start over other vehicles (Société de Transport de Montréal, 2011a). Only 2,957 trips were made by buses equipped with TSP during the study period. Routes 467 are served by both articulated buses and regular low floor buses. Around 9,864 of the total trips were made by articulated buses.

In this research I concentrate on two statistical models to capture and isolate the effects of the improvement strategies made by STM during the study period[1]. Table 3.1 includes a list of variables to be incorporated in the statistical analysis. According to previous studies, the factors affecting running time include passenger activity, passenger activity associated with articulated buses, number of stops made, time of the day, delays at the beginning of a trip, bus type and weather conditions.

The first running time model is a general one that captures the overall impact of all changes made by STM during the study period. AVL/APC data from January 2007 to April

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[1] In this dissertation, linear regression models have been used for the sake of clarity, simplicity and comparability with other research done in the literature. The main goal of this research is to understand the impact of service improvement strategies on service quality and users' perceptions, which have been done using the most common modeling techniques in the literature (as we can see in Table 2.2 and 2.4). Other advanced modeling techniques, such as multilevel linear regression or mixed effects models, could be tested and utilized in the future.

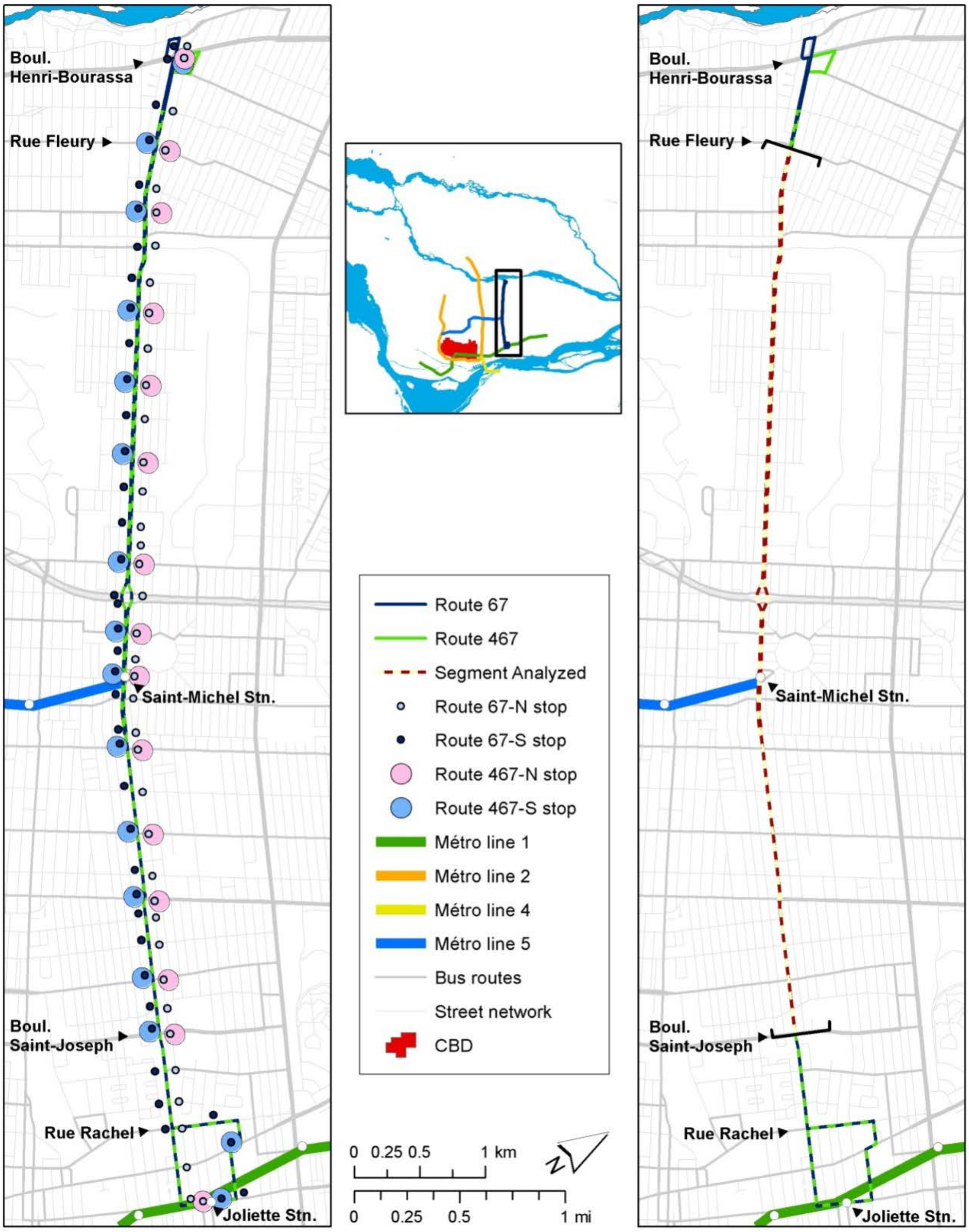
2007 is included as well as data from January 2011 to April 2011. The key variable in this model is *Y2011,* a dummy variable that will distinguish between the two. This variable will capture the impact of all the changes made on route 67. A positive value indicates an increase in the overall running time, whereas a negative one indicates a decline and improvements in running time along route 67. Since route 467 did not exist during the 2007 period, the Y2011 variable needs to be combined with the 467 dummy to quantify the level of improvement that route 467 brought to this corridor. The model specification is:

> *Running time = f(Maximum passenger load, Actual stops made, Total passenger activity (boardings and alightings), Precip rain (mm), Snow on the ground (cm), Route 467, Northbound trip, Delay at the start of the trip, AM Peak trip, PM Peak trip, Night trip, Midnight and early morning trip, Y2011)……………….1*

The second running time model contains dummy variables to control for the implementation of a smart card system, reserved lanes, limited-stop service, articulated buses and TSP. A dummy, *Smart Card Start*, distinguishes the trips made after the introduction of a new smart card payment system. According to STM, by the end of 2008, about a half million smart cards were in circulation (Société de transport de Montréal, 2009), therefore the study includes another variable called *'smart card by the end 2008'* to distinguish the trips made after this date, in order to demonstrate the real effect of the implementation of a smart card system. A second dummy variable is included, *Reserved Lane*, to distinguish trips made after the implementation of the reserved lane. Reserved lanes are operated on weekdays between 6:30 A.M. and 9:00 A.M. southbound and between 2:30 P.M. and 6:30 P.M. northbound. A third dummy variable, *Articulated buses*, characterizes articulated buses in operation along Route 467. A dummy variable to distinguish all the trips made after this date, called '*After articulated buses date*' is included. This dummy will help in showing the effect of articulated buses on the running time of other buses along the corridor. A dummy variable called '*TSP*' is used to distinguish TSP equipped buses from others. It is important to note that all TSP equipped buses are articulated and operating on route 467. Finally, a dummy variable called '*After TSP dat*e' distinguishes all trips made after the implementation of TSP to measure the impact of TSP on unequipped buses. The model specification is:

> *Running time = f(Maximum passenger load, Actual stops made, Total passenger activity (boardings and alightings), Articulated passenger activity (boarding and alighting on an articulated bus), Rain (mm), Snow on the ground (cm), Route 467, Northbound trip, Delay at the start of the trip, AM Peak trip, PM Peak trip, Night trip, Midnight and early morning trip, Smart card start, Smart card by the end of 2008, Reserved bus lane in operation, After articulated buses operation date, Articulated buses, After TSP implementation date, TSP equipped buses) ….2*

An explanation of each variable used in both models is presented in Table 3.1. The second part of the analysis compares the actual running time changes to riders' perceptions. A short field survey (one page including a French and English section) was carried out in June 2011 among 354 users at stops serving both routes 67 and 467 (Appendix 1). Passengers were asked which route (Route 67 or 467) they used most often and how frequently they used it. They were also asked to evaluate their travel and waiting time and compare it to the period when they started using either route 67 and 467. The survey requested riders to report their boarding and alighting stations. The survey also asked riders to indicate the dates they started using either route.



Data Sources: STM & DMTI

Projection: NAD 1983 MTM 8

Figure 3.2: Study routes and the analyzed segment

Table 3.1: Description of variables used in the regression models

Variable Name	Description
Running Time (seconds)	The running time per trip in seconds
Y2011	A dummy variable that equals 1 if the trip took place from January to April, 2011. When it is equal to 1, the variable signifies trips made after the implementation of all measures, a smart card fare collection, limited-stop bus service, reserved bus lane, articulated buses, and transit signal priority (TSP).
R467	A dummy variable that equals 1 if the trip is serving route 467
N	Dummy variable for northbound trips
Total Passenger Activity	The total number of passengers boarding or alighting during a trip.
Articulated passenger activity	The total number of passengers boarding or alighting on an articulated bus during a trip.
Maximum Load	The maximum load during a trip.
Actual stops made	The number of actual stops made by a given bus during a trip
Precip (mm)	The amount of rainfall in millimetres (1 mm of precipitation = 1 liter per square metre) on the day of the trip.
Snow (cm)	The amount of snow on the ground in centimetres on the day of the trip
Delay at start (s)	The delay at the beginning of the route in seconds, which equals the leave time minus the scheduled time at the first stop
Delay at end (s)	The delay at the end of the route in seconds, which equals the leave time minus the scheduled time at the last stop
AM Peak	A dummy variable that equals 1 if the trip took place between 6:30 am and 9:30 am
PM Peak	A dummy variable that equals 1 if the trip took place between 3:30 pm and 6:30 pm
Night	A dummy variable that equals 1 if the trip took place between 6:30 pm and 12:00 am
Midnight	A dummy variable that equals 1 if the trip took place between 12:00 am and 6:30 am
Smart card start	A dummy variable that equals 1 if the trip took place after the introduction of a new smart card payment system (OPUS) on April 1st, 2008
Smart card by the end of 2008	A dummy variable that equals 1 if the trip took place after the widespread use of the new smart card payment system (OPUS) on December 31st,2008
Reserved lane	A dummy variable that equals 1 if the trip observed is recorded using the reserved bus lanes. When equal to 1, the variable designates trips made after August 3rd, 2009, and between 6:30 A.M. and 9:00 A.M. southbound and between 2:30 P.M. and 6:30 P.M. northbound when the reserved lane is functioning.
After articulated buses date	A dummy variable that equals one if the trip observed came after the use of articulated bus service on boulevard Saint-Michel in February 1st, 2010.
Articulated buses	A dummy variable that equals 1 if the trip observed is recorded using an articulated bus.
After TSP date	A dummy variable that equals 1 if the trip observed comes after the use of TSP equipped buses on boulevard Saint-Michel in September 1st, 2010.
TSP	A dummy variable that equals 1 if the trip observed is recorded using TSP equipped buses.

3.5 ANALYSIS

3.5.1 Descriptive Statistics

Table 3.2 presents summary statistics for Route 67 and 467. The table compares the following six variables at the trip level of analysis: running time, total trip passenger activity, actual stops made, delay at the start, delay at the end, and trip maximum passenger load. Also in the table, route statistics are differentiated by two periods. Start period represents the situation before implementation of any measures, from January to April of 2007 for Route 67, and from May to July of 2009 for Route 467. For 2011, the period from January to April represents the route situation after the implementation of studied measures along the routes. Furthermore, Figure 3.1 presents the averages of bus running time and passenger activity in relation to each strategy that was implemented along Routes 67 and 467.

Table 3.2: Descriptive Statistics for start period and 2011 period

	Route 67				**Route 467**			
	Start (from January to April 2007)		Year 2011 (from January to April 2011)		Start (from May to July 2009)		Year 2011 (from January to April 2011)	
	Mean	Std. Dev.	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Running Time (s)	1662.2	170.9	1688.3	198.9	1526.7	129.4	1535.2	185.2
Passenger activity	155.1	63.0	131.9	54.4	123.5	48.4	137.4	67.6
Actual stops made	24.6	3.1	22.3	3.4	12.7	0.7	12.5	0.9
Delay at start (s)	38.2	89.5	56.3	114.6	56.2	105.3	64.7	131.3
Delay at end (s)	32.9	145.2	149.7	192.8	-100.5	154.1	81.52	189.2
Max. passenger load	43.5	15.4	37.4	13.1	39.1	13.8	44.5	20.8
Average speed (km/h)	14.8		14.5		16.1		16.0	
Number	2538		2548		348		2001	

3.5.2 Running Time Models

Two linear regression models are developed using running time in seconds, between boulevard Saint-Joseph and rue Fleury for Routes 67 and 467, as the dependent variable.

Table 3.3 presents the results of these models. The first model, which concentrates on the 2007 and 2011 periods, contains 6,478 trips and explains 62% of the variation in running time.

The key policy variable '*Y2011'*, which accounts for the difference in the running time between 2007 and 2011 on route 67, has a positive coefficient. This indicates that trips made during the after period (January to April 2011) are slower by 56.11 seconds compared to trips made between January and April 2007, while maintaining all other variables at their mean values. Although STM has implemented several strategies to improve running time along the corridor, such as express bus service, an exclusive lane, TSP, the introduction of the smart card system, and the use of articulated buses along this corridor, collectively we see a greater positive impact on running time (added more time), which is confirmed in the next model. Regarding the second policy variable '*R467,*' it is clear that route 467, which was not present in 2007, is faster than route 67 by 134 seconds southbound and by 224 seconds northbound. Since both northbound and southbound trips are the same distance and have an equal number of signalized intersections, the difference in running times between the two could be explained by traffic conditions. Nevertheless, these savings are 8.2% and 13.4%, which is consistent with previous studies (El-Geneidy & Surprenant-Legault, 2010; Surprenant-Legault & El-Geneidy, 2011). Accordingly the actual difference in running time between a bus serving route 67 in 2007 and a bus serving route 467 in 2011 is 78 seconds for southbound trips and 168 seconds for northbound trips. This model enables a better understanding of the combined impact of all operational improvement strategies introduced by STM along the studied routes.

The remaining variables in the models follow the expected sign and power. For every stop made along the routes, 5.03 seconds is added to the running time for dwell time, acceleration and deceleration at each stop. The total passenger activity (boarding and alighting) increases running time by 1.39 seconds per passenger. For every millimetre of rainfall, running time is expected to increase by 0.79 seconds per trip, while for every centimetre of snow on the ground running time increases by 1.81 seconds per trip. This finding is consistent with previous studies (El-Geneidy & Vijayakumar, 2011; Surprenant-Legault & El-Geneidy, 2011). Buses starting late compared to those on schedule are generally faster. This is because bus drivers normally try to compensate for any delay at the outset. Running time decreases by 0.22 seconds for every second of delay at the beginning of the route. Trips during PM peak are much longer (49.5 seconds) than midday trips, which is expected due to congestion and the increase in demand. Trips made during AM peak, night, and midnight are faster, by 47.03, 100.47, and 219.16 seconds respectively, compared to midday trips, which is also consistent with previous studies (Tétreault & El-Geneidy, 2010).

Table 3.3: Running time models

	2007 data (from January to April) and 2011 data (from January to April)		All data (from January 2007 to April 2011)	
	Coefficients	t	Coefficients	t
Constant	1425.73***	92.86	1395.80***	266.07
Maximum Passenger Load	-0.40*	-2.03	-0.75***	-10.00
Actual stops made	5.03***	7.36	5.21***	21.38
Total passenger activity	1.39***	24.31	1.56***	71.86
Articulated passenger activity			-0.21***	-7.78
Precip	0.79**	2.54	0.52***	6.60
Snow	1.81***	9.57	1.07***	13.95
R467	-134.32***	-15.75	-123.75***	-35.57
N	-89.79***	-29.16	-60.22***	-56.58
Delay at start (s)	-0.22***	-15.95	-0.17***	-35.11
AM Peak	-47.03***	-10.79	-33.59***	-21.65
PM Peak	49.54***	11.61	60.14***	38.93
Night	-100.47***	-20.99	-99.94***	-62.21
Midnight	-219.16***	-30.63	-212.50***	-87.35
Y2011	56.21***	14.10		
Smart card start			5.83***	3.15
Smart card by the end of 2008			46.81***	24.79
Reserved lane			-35.26***	-20.08
After articulated buses date			26.80***	14.68
Articulated buses			43.62***	10.24
After TSP date			-4.76**	-2.64
TSP			-13.56***	-4.37
N	6,478		60,973	
R2	0.62		0.59	

*** Significant at 99.9% ** Significant at 99% * Significant at 95%

Regarding the second detailed running time model, it is clear that the model adheres to the same signs and magnitude as the previous model. The introduction of the smart card (OPUS) fare collection system on buses starting April 1st, 2008 increased the running time of trips on route 67 by 5.83 seconds. By the end of 2008, this value further increased by 46.8 seconds to reach 52.61 seconds. This increase is related to a jump in the number of smart card users compared to passengers using traditional flash passes, a finding that is consistent with previous work (El-Geneidy & Surprenant-Legault, 2010). As would be expected, the implementation of the reserved bus lanes along boulevard Saint Michel decreased running time by 35.26 seconds on average. This savings in running time due to the use of reserved lanes is considered small. One explanation for this is the effect of cars waiting in this lane to turn right at a traffic light, as cars cannot turn right on red lights on the island of Montréal (Surprenant-Legault & El-Geneidy, 2011).

The introduction of articulated buses increased the running time by 26.80 seconds along the corridor. Although articulated buses run only on Route 467, this increase is due to the high frequency of service along the two routes. In many cases buses are closely behind each other, as the average headway for Route 467 and Route 67 is only 7 minutes during peak hours. The use of an articulated bus adds 70.4 seconds along Route 467, which is the combined effect of the 43.62 seconds associated with the use of an articulated bus and 26.80 seconds associated with the time it takes to implement this service. However, this value does not explain the true effect of an articulated bus on running time. Operation of an articulated bus has a mixed effect on running time, increasing time associated with acceleration, deceleration and merging with traffic, and decreasing time associated with passenger activity. Hence, the model includes an '*articulated passenger activity*' variable which captures the savings in dwell time by 0.2 second per passenger (and the average passenger activity per trip is 126), indicating a savings of 26.3 seconds in dwell time. Accordingly, operating an articulated bus adds 44.1 seconds of running time, which is consistent with previous studies (El-Geneidy & Vijayakumar, 2011). Furthermore, since the majority of operated buses along Route 467 are articulated, the difference in Route 467 savings between the two regression models can be also explained.

Around 50 operated articulated buses along Route 467 are outfitted with a TSP system (Société de Transport de Montréal, 2011a). After the introduction of these buses on September 1st, 2010, the total travel time decreased by 4.76 seconds (0.3%) for all buses serving the corridor, even if they were not equipped with TSP. For TSP-equipped buses, the total running time savings reached 18.32 seconds (1.2%). According to previous reports in transit literature, TSP benefits are not consistent across routes and time periods. Nevertheless, it is possible that the benefits of the TSP system are mitigated because of the corridor’s physical factors and system design (e.g., AVL and signal controller logic), as well as operational factors, for example excess traffic congestion and other events which cause delays. Therefore, a more detailed study concerning TSP operation along the corridor is required in order to determine ways of maximizing the benefits.

Using the second running time model coefficients, it is possible to estimate the changes in running time by conducting a sensitivity analysis that predicts the changes in average running time for each route, while holding all variables constant at their mean values. This sensitivity analysis enables a better understanding of the synergetic impact of each change in the operational environment. Table 3.4 presents the estimated running times and the percentage of change compared to the initial Route 67 situation. As this table indicates, the introduction of OPUS increased running time along Route 67 by 3% on average compared to the initial Route 67 situation. Running time in general declined by 0.3% along Route 67 after the implementation of the limited-stop service (Route 467), mainly due to a decline in the number of passengers using Route 67. For route 467, the running time savings was around 11% on average compared to the initial Route 67 situation, a drop in running time related to the decline in the number of stops and to the number of passengers using the route per trip. Since the reserved bus lanes operated only northbound at PM peak and southbound at AM peak, the savings along Route 67 and 467 trips using these lanes were 1.7% and 13% respectively, compared to the initial Route 67 situation. On the contrary, trips running northbound at AM peak and southbound at PM peak did not benefit from the reserved lanes as they are implemented on the other side of the corridor.

Following the use of articulated buses along Route 467, running times declined by 10.2 % and 10.5 % for those buses using the reserve lanes, and by 8.2% and 8.7% for other trips not benefiting from the reserved lanes. The operation of articulated buses along Route 467 affected Route 67 performance, increasing running time by 0.2% and 0.4% on average for those trips using the reserved lanes and by 2.2% and 2.4% for other trips. The installation of a TSP system on articulated buses decreased running time by 11.3% and 11.5% on average compared to the initial Route 67 situation for buses using reserved lanes, and by 9.3% and 9.8% for other buses not using the reserved lanes. Also for Route 67, the running time decreased by 0.1 % for buses using reserved lanes, and by 2% for other buses. Finally, it is clear that after the implementation of all measures, Route 467 is collectively faster by 10.2 % on average, while Route 67 is slower by 1% on average, compared to Route 67 in the initial situation.

Table 3.4: Estimated running time in seconds and the percentage of change*

Route 467

Scenario	Initial Situation	Reserved Lanes	Articulated Buses	TSP
North AM Peak	1440 (-11.5%)		1486 (-8.70%)	1467 (-9.8%)
North PM Peak	1534 (-10.8%)	1498 (-12.9%)	1544 (-10.2%)	1526 (-11.3%)
South AM Peak	1500 (-11.1%)	1465 (-13.2%)	1511 (-10.5%)	1492 (-11.5%)
South PM Peak	1588 (-10.8%)		1634 (-8.2%)	1616 (-9.3%)

Route 67

Scenario	Initial situation	OPUS	After the limited-stop service	Reserved Lanes	After Articulated date	After TSP date
North AM Peak	1627	1677 (3.1%)	1632 (0.3%)		1665 (2.4%)	1661 (2.1%)
North PM Peak	1720	1770 (2.9%)	1725 (0.3%)	1690 (-1.7%)	1724 (0.2%)	1719 (-0.1%)
South AM Peak	1687	1737 (3.0%)	1692 (0.3%)	1657 (-1.8%)	1694 (0.4%)	1686 (-0.1%)
South PM Peak	1781	1831 (2.8%)	1787 (0.4%)		1819 (2.2%)	1815 (1.9%)

* Compared to Route 67 initial situations

To summarize, the various measures used by STM can be divided into two groups. The first group of implemented measures decreases running time along the analyzed corridor.

These measures include limited-stop bus service (10.8%), reserved bus lane (2.2%), and operation of TSP (1.2%). Meanwhile, the second group increases running time. These measures include implementation of a smart card system (3 %) and operation of articulated buses (2.8%). It is also important to note that a spillover effect takes place when it comes to using TSP and articulated buses, where non-articulated buses experience a decline in running time when operating parallel to articulated buses. In addition, non-TSP equipped buses experience savings by running parallel to TSP-equipped buses.

3.5.3 Survey Analysis

With credit to these improvements in service, the STM observed an 8% increase (around 3000 passengers) in total daily ridership on boulevard Saint-Michel between January 2007 and 2011. Therefore, an evaluation of customer satisfaction and perception of time savings after the implementation of these strategies was necessary.

A survey was carried out in June 2011 among 354 users of routes 67 and 467 at five northbound stops and seven southbound stops served by both routes. This 95% confidence level sample size represents a confidence interval of 5.2% of the average daily ridership users' opinions along the corridor. The data revealed that 51.7% of the respondents used route 467 most often compared to 29.4% for route 67, while 18.9% of the respondents indicated that they used both routes equally. The survey found that around 28.8% of the respondents changed their usual stop, the one nearest to their point of departure or arrival, in order to use Route 467. In other words riders were willing to walk longer distances to avail themselves of the faster service. Around 63.3% of respondents indicated that they used Route 67 and/or Route 467 almost 5 days a week or more, while 25.7% and 11% indicated that they used these routes either two to four days a week or one day a week or less, respectively. Around 52.8% of Route 67 passengers indicated that they had been using this route before the implementation of OPUS smart card. Meanwhile, around 53.1% of Route 467 passengers indicated that they shifted to this route when it started in 2009 or they were new users of the 467 service. Riders were asked to indicate their boarding and alighting stops as well as the date when they started using the route. Each rider surveyed was asked to indicate the average amount of time savings that he/she estimated over a period. Table 3.5 presents a summary of the survey findings in terms of perceptions of running time savings. Confidence intervals for these questions range from 7.2% to 9.2% at 95% confidence level. In this table, the perceived change in waiting and travel time is differentiated by route number.

As seen in table 3.5, while 49.2% of riders noticed that their travel time decreased compared to when they started using the bus services along Route 467, only 7.1% felt a longer commute, and 43.7% did not notice a change. For route 67, the perception of a decrease in travel time reached 54.8%, with only 9.6% reporting an increase in their travel time, and 35.6% who did not see any change. Meanwhile, 55.2% of Route 67 or/and Route 467 users, accessing either route depending on the availability of buses, felt that their travel time decreased compared to when they started using the bus services along the corridor, while 7.5% felt a longer commute, and 37.3% did not notice a change.

In addition to an estimate of the amount of time saved, the survey asked riders to identify the bus stops they used for boarding and alighting, as well as when they started using either route. For every rider this information was compared with the average travel time changes archived in AVL data. Then, a difference in means t-test was used to compare perceptions of travel time changes to actual travel time changes. This test was performed only for Route 467 and 67 users.

Table 3.5: Users' perception of travel time savings

	Travel time		
Perception	Route 467	Route 67	Route 67 &467
Decrease in time	49.2%	54.8%	55.2%
Increase in time	7.1%	9.6%	7.5%
No change	43.7%	35.6%	37.3%
Number of observations	183	104	67
% of the sample	51.7%	29.4%	18.9%
confidence interval*	7.2%	8.5%	9.2%

* Confidence interval (also called margin of error) at the 95% confidence level

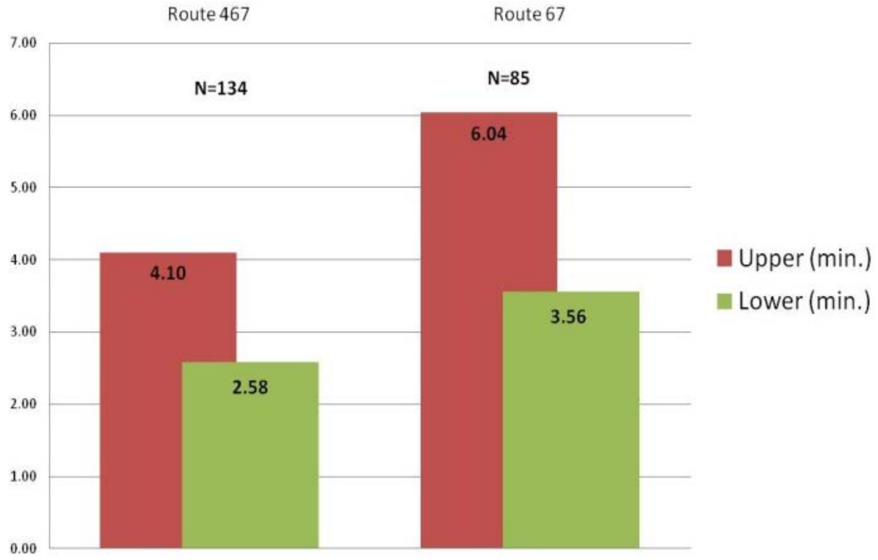


Figure 3.3: Users paired differences using means t-test

Figure 3.3 shows the users paired difference according to the route used. For route 467 riders, a statistically significant difference exists between their estimates and the actual savings from the time they started using the same route. Users overestimated their travel time savings within a range of 2.6 to 4.1 minutes. This amount of time represents around 9.6% to 16.1% of Route 467 average running time in 2009. For route 67, there was also a statistically significant difference between the perception of change and actual change. Users overestimated their travel time savings by 3.6 to 6.0 minutes. This represents around 12.6% to 21.7% of Route 67 running time during the initial situation in 2007. Generally, the studied set of measures along the Boulevard Saint-Michel corridor indicates that they have a positive effect on riders' perceptions. Although the majority of these measures are implemented for Route 467, the activation of the 467 service itself, reserved bus lanes, introduction of articulated buses, and TSP systems, Route 67 users sense more time savings than Route 467 users. One explanation for this difference is that a large percentage of Route 67 passengers started using the service before 2008, and they have witnessed all the measures that were implemented along the corridor.

3.6 CONCLUSION

The main objective of this chapter was to evaluate the impact of a combination of measures implemented along boulevard Saint-Michel in Montréal, Canada, with respect to bus running time and how these measures may function together. These measures, in chronological order, are the implementation of a smart card fare collection system (OPUS), limited-stop bus service (Route 467), reserved bus lanes, introduction of articulated buses, and TSP systems. After the implementation of these measures, analysis indicates that the limited-stop bus service (Route 467) provides a faster service by 10.5% on average, while the regular route (Route 67) is slower by 1% on average compared to the initial situation. A 10% decline in running time per trip can lead to substantial operational savings. In other words, the operating costs associated with 10 trips can be saved in a corridor that has 100 trips per day, where such strategies are implemented. These numbers could be augmented if some of the other measures were not in place along the studied corridor, specifically smart card implementation and the use of articulated buses. The introduction of a smart card system and the use of articulated buses had a greater negative impact (increased running time) than the positive ones (decreased running time) associated with the implementation of an exclusive lane, faster passenger activity along articulated buses, and TSP. For articulated buses, boarding is restricted to the front door and only allowed via the back door when the bus is overcrowded, owing to normal fare collection procedures. Therefore, moving fare collection off the articulated buses offers the greatest potential to use all doors in order to maximize benefits, particularly at high passenger activity stops like metro stations, such as Saint-Michel Metro stop. For reserved lanes and TSP, Montreal has a no turn on red traffic light policy which affects the line up of cars in front of a bus, though this can be partially addressed by locating stops on the far side of the street. It is important to note a negative spillover effect due to the presence of articulated buses in the corridor, which causes delays for other buses. Therefore, the mixing of articulated buses with regular ones is not recommended, so that such problems can be avoided in the future. Meanwhile, TSP equipped buses had a positive impact on non-TSP equipped buses, leading to time savings for these buses. It is important to note that the measures that lead to an increase in running time are generally known to be well received by customers. Benefits do exist from measures like implementing articulated buses, since they contribute to less overcrowding. At the same time, smart card systems are known for their benefits to agencies in reducing fraud.

The second objective of this chapter was to quantify to what extent the implemented strategies of the STM affected users perceived decrease in their travel time. While there was no actual savings in the running time of buses, users overestimated their travel time savings within a range of 2.5 to 6.0 minutes. This generally indicates that passengers have a positive attitude towards any improvements in service.

Finally, this chapter studied the effects of a combination of measures on the buses running time for two high-frequency routes sharing the same corridor. It is recommended that this work be expanded to investigate the effects of these measures on the variability of service. In addition, since not all STM buses are equipped with APC and AVL systems, it is not possible to study the actual headway changes with the data used in this study. Also, due to the limited effect of a TSP system on the running time along the corridor, a more detailed study concerning the factors affecting TSP operation and programming is required in order to maximize the benefits of the system.

3.7 ACKNOWLEDGEMENTS

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4 CHAPTER FOUR: VARIATION IN BUS TRANSIT SERVICE: UNDERSTANDING THE IMPACTS OF VARIOUS IMPROVEMENT STRATEGIES ON TRANSIT SERVICE RELIABILITY

4.1 OVERVIEW OF CHAPTER

Transit agencies wishing to offer reliable service with less variability compared to schedules face several challenges, thus encouraging them to employ various strategies. The previous chapter (Chapter 3) investigates the overall impact of a set of strategies on running time at the route level of analysis, which was one of the main goals these strategies were implemented to achieve. This chapter (Chapter 4) expands on those results to cover the impact of previous STM improvement strategies and their synergies on the variation of transit service at the segment level of analysis. Using the segment level of analysis provides a more detailed and fine-grained understanding of the effects of improvement strategies on running time, running time in relationship to schedule, and their variation, which relates more to users' experiences. This chapter echoes the previous chapter's finding on a different scale of analysis, while adding valuable information associated with the effects of various strategies on different aspects of service variation. Indeed, service variation is an important aspect of transit service reliability that impacts the productivity and service quality of transit agencies. This chapter examines the impact of the previous improvement strategies on running time deviation from schedule, variation in running time, and variation in running time deviation from schedules along the same bus corridor (Saint-Michel bus corridor).

This chapter uses AVL/APC systems data at the bus route segment level of analysis. It reveals that the introduction of a smart card fare collection system increased bus running time and service variation compared to the situation before which saw the use of traditional flash passes, while other analyzed strategies have mixed effects on variation in comparison to the running time changes. This study offers transit agencies and schedulers a unique understanding of the effects of various strategies on different aspects of service variation, which are important components of transit service provision, though they are rarely discussed in the literature, as pointed out in Chapter 2.

4.2 INTRODUCTION

Transit agencies implement various strategies in order to enhance service and provide transportation that can compete with other transport modes, such as the private automobile. Between 2008 and 2011, the Société de Transport de Montréal (STM), which operates the transit service on the island of Montreal, Canada, considered various measures for improving bus service along the Saint Michel corridor. This corridor receives special attention from the STM since it is heavily used, with an average total daily bus ridership of 43,000 passengers. The measures implemented by STM started in April 2008 with the introduction of a new smart card fare collection system named OPUS. OPUS replaced the traditional flash passes and provided passengers with a more appealing and convenient payment option (Société de transport de Montréal, 2010). At the end of March 2009, the STM introduced a limited-stop service identified as Route 467, running parallel to the regular service of Route 67 along the corridor, but serving only 40% of the regular route stops. The introduction of Route 467 led to a decline in Route 67 service frequency (6.1 minutes to 8.2 minutes headway). During the study period, both bus routes had an average headway of 7 minutes during peak hours.

In order to improve service efficiency along the corridor, at the beginning of August 2009 the STM introduced reserved lanes functioning during peak hours. Starting at the beginning of February 2010, the STM operated several articulated buses along Route 467. Finally, in September 2010, the STM outfitted a few articulated buses along route 467 with a transit signal priority (TSP) system, giving these buses priority over other road vehicles at all corridor signals. Figure 4.1 presents a timeline of the strategies implemented by the STM along the studied routes between January 2007 and April 2011.

The temporal differences resulting from the implemented strategies offer a unique opportunity to consider their impact on service attributes and examine the synergies between them. The previous chapter (Chapter 3) investigates the overall impact of these strategies on running time at the route level, which is one of the main goals these strategies were implemented to achieve. However, this information presents only one important component of the truth and ignores any side effects that the strategies could have on variation in the service. The effect of these strategies on service variation is an important aspect of service provision. Transit agencies pay a lot of attention to variation of transit service because such variation directly affects the amount of recovery time added to schedules and service productivity. Transit agencies are also interested in providing reliable service that is fast and consistent from day to day to increase passenger satisfaction. This is due to the fact that passengers are concerned with day-to-day variability in bus service performance, which affects their decision-making and time-management processes. Additionally, an increase in service variation can result in the need for new buses to maintain the same level of frequency, whereas a reduction in variation can offer the opportunity to add additional trips since recovery times added to schedules are reduced.

This chapter aims to provide an understanding of the impact of various measures implemented by the STM on bus running time variation. It also aims to understand bus running time variation in relation to schedules at the segment level. This study employs a wide array of archived data obtained from the STM’s automatic vehicle location (AVL) and automatic passenger count (APC) systems for Route 67 and Route 467. The chapter starts with a literature review concerning the effects of various measures on both running time and running time variation, followed by a methodology section describing the data and methods used. This is followed by an analysis section which includes the results of the models along with a detailed discussion. Finally, the chapter ends with a conclusion section outlining its major findings and its policy implication for transit planners and operators.

4.3 LITERATURE REVIEW

While bus transit service is the dominant type of public transit in most Canadian and American cities (American Public Transportation Association, 2011a, 2011b), it is also the most sensitive transit service in terms of being subject to expected and unexpected events (El-Geneidy et al., 2006; Kimpel, 2001; Kittelson & Associates, KFH Group, et al., 2003; Strathman et al., 2000). Transit agencies are challenged to provide attractive services to bus transit users. Passengers are concerned about the day-to-day variability in bus service performance, and consider transit to be more reliable only when it (a) decreases their efforts to access the service at both origin and destination (Hensher et al., 2003; Murray & Wu, 2003); (b) has a low waiting time at stops; and (c) has a short and consistent travel time from day to day (El-Geneidy et al., 2011; Koenig, 1980; Murray & Wu, 2003).

Researchers indicate that the value people place on travel time and travel time variation are nonlinear (Pinjari & Bhat, 2006). The cost of travel time variation may in fact be greater than the cost of regular travel time (C. Chen et al., 2003; Perk et al., 2008), greatly affecting decision-making and daily time-planning processes (Bates et al., 2001; Nam et al., 2005; Noland & Polak, 2002). Increases in service variation for users are associated with increases in their waiting times at bus stops, increasing their anxiety levels, while reducing the perceived comfort, which result in decreasing attractiveness of the service (Bates et al., 2001; Perk et al., 2008). Researchers indicate that a service with smaller deviations in relation to schedule is more appreciated by the public than a shorter headway service (Balcombe et al., 2004; Daskalakis & Stathopoulos, 2008). Balcombe et al. (2004) state that passengers consider service reliability twice as important as bus frequency (number of trips per hour). Furthermore, improvement in service running time and running time variability have both been linked to increases in ridership and the satisfaction level of riders (Boyle, 2006; Hensher et al., 2003; Hollander, 2006).

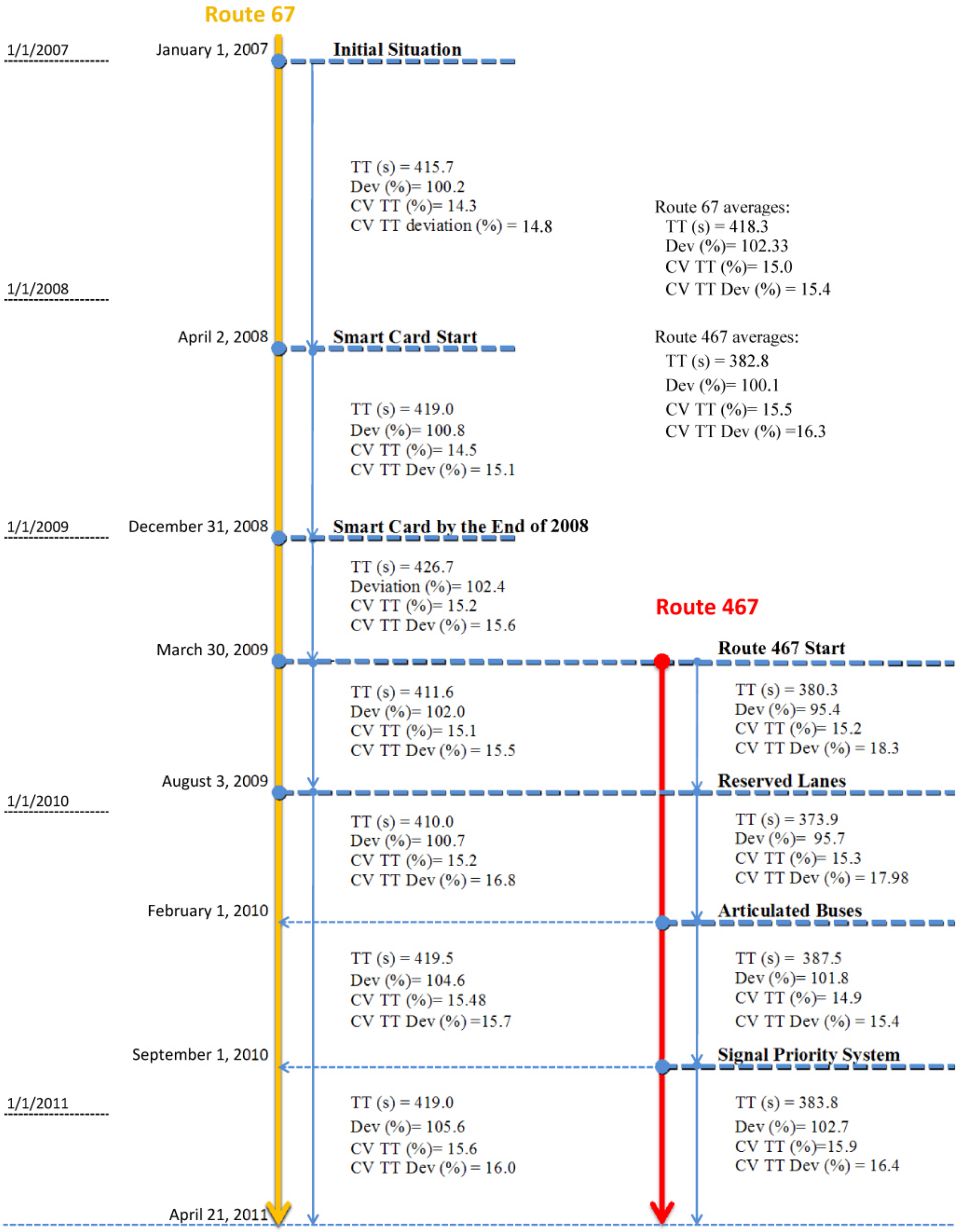
Running time is the amount of time that it takes for a bus to travel from point A to B along a designated route serving passengers. Various basic factors have been identified by researchers as affecting bus running time. These factors include distance, passenger activity (passenger boarding and alighting), the built environment of the routes (such as number of signalized intersections), delay at the start, period of the day, number of actual stops made, environmental factors (such as rain and snow), and traffic conditions (Abkowitz, 1983; El-Geneidy et al., 2011; H. Levinson, 1983; Strathman et al., 2000). These factors are also strongly believed to influence running time variability (Abkowitz, 1983; El-Geneidy et al., 2011; Kimpel, 2001; Sterman & Schofer, 1976). Accordingly, agencies implementing different strategies, such as smart card fare collection systems, reserved bus lanes, limited-stop bus services, articulated buses, and TSP, expect an impact on both running time and running time variation (Tann & Hinebaugh, 2009).

Many researchers have investigated the effects of different strategies on running time (Diab & El-Geneidy, 2012; El-Geneidy & Vijayakumar, 2011; Kimpel et al., 2005; Surprenant-Legault & El-Geneidy, 2011). However, less attention has been given to the impact of these strategies on the variation of service, since variation is more difficult to address (Schramm et al., 2010). Several studies concur that limited-stop bus service and reserved bus lane decrease running time (El-Geneidy & Surprenant-Legault, 2010; Surprenant-Legault & El-Geneidy, 2011), while TSP systems have uncertain effects on running time (Kimpel et al., 2005). The use of articulated buses along a transit corridor is expected to have a mixed effect on running time. The first is a negative effect which increases running time due to acceleration, deceleration and manoeuvring time. The second is a positive effect which decreases running time due to a decline in the time associated with passenger activity (El-Geneidy et al., 2011). The use of the smart card has a general negative effect by increasing running time compared to the use of flash passes (El-Geneidy & Surprenant-Legault, 2010; Kittelson & Associates, KFH Group, et al., 2003; Surprenant-Legault & El-Geneidy, 2011).

To understand the effect of various strategies on running time, researchers generated running time models and analyzed the effects of these measures using before and after AVL/APC archived data through isolating the impact of each strategy. Using AVL/APC data is common in the transit literature (El-Geneidy et al., 2006; Kimpel, 2001; Kimpel et al., 2005). Other researchers have focused on generating performance measures that determine and accommodate service variability. For example, Camus et al. (2005) proposed a new measure called Weighted Delay Index to overcome an on time performance (OTP) shortcoming, which is recommended by *the transit capacity and quality of service manual (TCQSM)*, in order to better understand service reliability (Kittelson & Associates, KFH Group, et al., 2003). Lin et al. (2008) used AVL data and a framework involving Data Envelopment Analysis (DEA), to generate a comprehensive measure of service reliability. Using different methodology, similar research has been done by Fu et al. (2007) to introduce a measure called Transit Service Indicator (TSI), combining multiple performance measures. Later on, Chen et al. (2009) and Saberi et al. (2012) generated different measures to assess service variation and reliability.

Other researchers have focused on understanding the general factors affecting the variation through simple measures of variation (Abkowitz, 1983; El-Geneidy et al., 2011). The work of Abkowitz and Engelstein (1983) is among the earliest studies on running time variation. They investigated running time variation at the route-segment level of analysis, and found that variation tends to escalate as vehicles move along a route, having included a variable to control for the existing levels of variation. Kimpel (2001), using AVL/APC from TriMet, Portland, provided a framework for analyzing transit service reliability and especially variation at the time point level of analysis, and incorporated headway delay variation and departure delay variation as measures. He found that the amount of delay variation at the previous time point affects the amount of headway delay variation and departure delay variation. Later, one study analyzed AVL data obtained from Metro Transit, Minnesota, by using running time deviation and the coefficient of variation (CV) of running time models (El-Geneidy et al., 2011).

However, none of the aforementioned studies have focused on understanding the impact of the implementation of various strategies on service variation. One study by El-Geneidy et al. (2006) used AVL/APC data from TriMet to analyze bus service variation after the implementation of a bus stop consolidation project, using a running time and CV of running time model, while controlling different influential variables. They revealed that while running time had improved by 6% at the segment level, there was no evidence of any changes in running time variation, which can be associated with the length of the segment under study. Other studies used simple descriptive statistics to break down the impact of the implementation of TSP (Kimpel et al., 2005) and to address various bus rapid transit (BRT) features on running time variation (Schramm et al., 2010), without isolating different effects of influential variables on the service. Therefore, further investigation is required on the effect of the use of smart cards, limited-stop bus service, articulated buses, TSP and reserved lanes.



TT (s)= Segment running time (s)
Dev (%)= Running time deviation (%)
CV TT (%)= CV running time (%)
CV TT Dev (%)= CV running time deviation (%)

Figure 4.1: Time line of changes made to bus service on Boulevard Saint Michel

4.4 METHODOLOGY

The objective of this analysis is to understand the effect of various strategies implemented by STM on buses' travel time variation and deviation from the schedule at the segment level. The data used in the analysis comes from a sample of STM's AVL and APC archived data system for routes 67 and 467. As only around 18% (306 out of 1,680 buses) of STM buses are equipped with AVL and APC systems, the STM operates these buses on different routes in order to understand overall service quality and to adjust schedules. Routes 67 and 467 run for approximately 9.4 km along the eastern side of Montreal's Central Business District (CBD). They cross through five boroughs of the City of Montreal, and connect two metro stations. The two routes share Boulevard Saint-Michel, which consists of three lanes in each direction. The built environment along the boulevard is mainly comprised of two to three story residential buildings with a concentration of commercial ventures, such as parking lots and storage areas, at the north end. There have been no significant changes along the corridor over the last five years in terms of the built environment. The average stop spacing is 615 metres for Route 467 and 245 metres for Route 67. Figure 2 shows Route 467 and Route 67 as well as the analyzed segments[2]. All signalized intersections are equipped with TSP along the analyzed segments, which extend the green traffic lights or activate the priority system for outfitted TSP buses (Société de Transport de Montréal, 2011a). The reserved bus lane is the far right one in each direction, closest to pedestrian sidewalks, designated by paint and signage. However, private automobiles are allowed to use these reserved lanes during operation hours to turn right. Different types of intersections can be found along the boulevard, from 3-way (including T intersections and Y intersections) to 4-way.

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[2] Four segments have been identified in order to provide a more detailed and fine-grained understanding of the effects of various strategies on different aspects of service variation. The segments were chosen according to some of the corridor's main intersections, time points, and were located at stops that are served by both routes.

Over 2,250,000 individual stop observations for routes 67 and 467 were collected from the STM's archival data between January 1st, 2007 and April 21st, 2011. Individual stop data includes bus arrival, departure, and schedule times along the route, as well as information about passenger activity and load, trip number and direction, and bus type. Since trip segment is the chapter's unit of analysis, all variables were summarized according to trip segment, for example passenger activity per trip segment. After cleaning the source data and removing system recording errors, holiday and weekend trips, layover time and segments with insufficient passenger activity (less than 3 passengers per trip segment (less than 1% of the total number of trip segments)), 255,000 trip segments were included in the final database. For each of these trip segments the percentage of running time deviation from schedule was calculated by dividing actual running time per trip segment by scheduled running time per trip segment, and then multiplying the outcome by one hundred.

The objective of this analysis is to understand the effect of each strategy implemented by STM on bus travel time variation and deviation from the schedule at the segment level of analysis. Data from the trip segments is aggregated according to the following criteria: the implemented strategy, time of the day (am peak, pm peak, midday, night, and midnight or early morning), type of bus (articulated or regular buses), route number (route 467 or 67), and direction (north or south). For example, all Route 467 northbound trips completed by regular buses using the reserved lanes, during the afternoon peak, after the introduction of articulated buses along the corridor and before the implementation of TSP system along the first segment, are aggregated into one category in order to discern their travel time range of variation. This is done by calculating the average and standard deviation of running time for this group of trips and then calculating the CV of running time, and the CV of running time deviation from the schedule. Furthermore, to ensure robustness of the generated data, several sample sizes were tested to distinguish how many trip segments at minimum should be included to derive the group averages and standard deviations. A group of 25 trip segment observations was found to be a good sample size for a group to maintain its robustness. Accordingly, after this process, 478 groups of trip segments were retained. The groups included in analysis represent more than 99% of all trip segment observations with an average group size of 530 trip segment observations. The following formulas describe the above calculations:

Running time deviation (%) = (the actual running time per trip segment / the scheduled running time per trip segment) * 100 (1)
CV Running time (%)[3] = (running time standard deviation for a group / the group average running time)*100 (2)
CV running time deviation (%) = (running time deviation standard deviation for a group / running time deviation average)*100 (3)

In this research I will be concentrating on four statistical models to capture and isolate the effects of the improvement strategies made by STM on bus running time variation and variation of deviation from schedule. A detailed description of each variable used in the models is presented in Table 4.1. The first model is the trip segment running time model. The purpose of the model is to understand the overall quality of data used in this study, to identify its consistency with previous research discussed in the literature, and to demonstrate the effects of the improvement strategies made by STM during the study period at the segment level. According to earlier studies, the general factors affecting running time include passenger activity, distance, passenger activity associated with articulated buses, number of stops made, time of the day, delays at the beginning of a trip, bus type and weather conditions (Abkowitz & Engelstein, 1983; Diab & El-Geneidy, 2012; Kimpel, 2001). A dummy for segment number is included in the models in order to isolate the built environment and land use, intersection, distance and corridor design effects on bus running time and variation.

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[3] Coefficient of variation (CV) provides a global measure to understand the bandwidth of the service's variation. It identifies the standard deviation of data in the context of the mean of the data, which is very useful to compare datasets with different units or different means. Therefore, it has been used in this chapter to understand the effects of various strategies on different aspects of service variation, while accounting for the differences between segments. Since CV is a unit free measure, it is normally presented as a percentage.

Furthermore, various dummy variables have been generated to control the impact of STM implemented strategies, including the introduction of a smart card system, limited-stop service, reserved lanes, articulated buses and TSP system.

Two dummies have been included in the models to demonstrate the real effect of using a smart card system. The first dummy is *Smart card start*, distinguishing the trips made after the introduction of the new smart card system in April 2008. The second dummy is *smart card by the end 2008*, distinguishing the trips made after the widespread use of the new smart card, since according to official reports around half a million cards were functional by the end of 2008 (Société de transport de Montréal, 2009). In addition, a dummy variable called *Reserved lanes* is included in the models, distinguishing trips that utilized the reserved lane. The reserved lanes are operated according to time and direction, from 2:30 P.M. to 6:30 P.M northbound and from 6:30 A.M. to 9:00 A.M. southbound. *Articulated buses* and *TSP buses* are two dummy variables that are also included in the models, to recognize articulated buses and buses outfitted with a TSP system, respectively. Finally, two dummy variables, *After articulated buses dat*e and *After TSP dat*e are included, distinguishing all the trips made after the date of the introduction of articulated buses and the TSP system along the corridor, respectively. These two variables help in identifying the effect of implementing articulated buses and TSP equipped buses serving Route 467 on all buses running along the corridor, including Route 67 buses.

The second model is the running time deviation percentage model, showing the effects of STM implemented strategies on running time in relation to the associated schedules, allowing us to recognize the real quality of service that people are experiencing. The third model is the CV of running time (%) model, which measures and captures the effect of the implemented strategies on running time variation, something highly appreciated by passengers, while controlling different influential variables. The fourth model is CV of running time deviation (%), which captures the difference between the trip segments' running time range of variation and the schedules' permitted level of variation after every implemented strategy by STM.

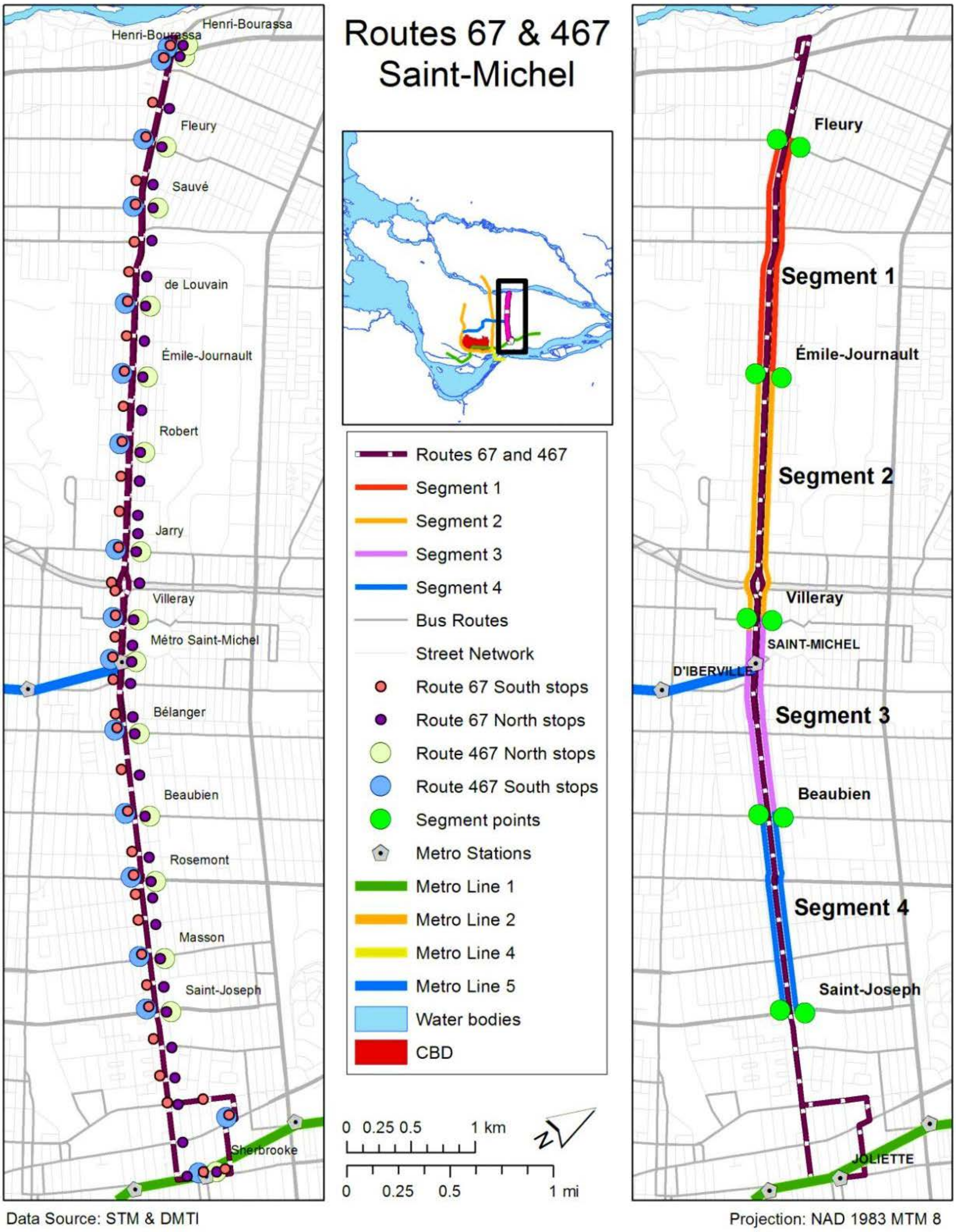

Figure 4.2: Study route segments

Table 4.1: Description of variables used in the regression models

Variable Name	Description
Segment running time (seconds)	The segment running time in seconds, which is the difference between leave time from the last stop of a segment and leave time of the first stop of a segment for a designated trip.
Segment running time deviation (%)	The actual running time divided by the scheduled running time multiplied by one hundred.
Route 467	A dummy variable equaling one if the trip segment occurs on Route 467.
Northbound	Dummy variable for northbound trips.
Segment passenger activity	Total number of passenger boardings and alightings per trip segment.
Articulated rear door activity	Total number of passenger boardings and alightings from articulated buses third door per trip segment.
Actual stops	Number of the actual stops made per trip segment.
Precip (mm)	The average of rainfall measured in millimetres on a day of the trip segment.
Snow (cm)	Snow precipitation in centimetres on the trip day.
Delay at the start (s)	The delay at the start of a trip segment in seconds, which is the difference between the leave time and the scheduled leave time at the first stop of a segment.
AM Peak	A dummy variable equaling one if the trip segment occurred between 6:30 am to 9:30 am and zero otherwise.
Midday	A dummy variable equaling one if the trip segment occurred between 9:30am to 3:30 pm and zero otherwise
PM Peak	A dummy variable equaling one if the trip segment occurred between 3:30 pm and 6:30 pm and zero otherwise.
Night	A dummy variable equaling one if the trip segment occurred between 6:30 pm and 12:00 am and zero otherwise.
Midnight and early morning	A dummy variable equaling one if the trip segment occurred between 12:00 am and 6:30 am and zero otherwise.
Smart card	A dummy variable equaling one if the data used for the trip segment were collected after the implementation of a new smart card fare collection system named OPUS on April 1st, 2008 and zero otherwise.
Smart card by the end of 2008	A dummy variable equaling one if the data used for this trip segment were collected after the December 31st, 2008 and zero otherwise, determining the spread of OPUS use.
Reserved lane	Dummy variable equaling one if the data used for this trip segment were collected after August 3, 2009, and between 6:30 A.M. and 9:00 A.M. southbound or between 2:30 P.M. and 6:30 P.M. northbound.
After articulated buses date	A dummy variable equaling one if the data used for this trip segment were collected after the introduction of articulated buses along Saint-Michel corridor on February 1st, 2010.
Articulated buses	A dummy variable equaling one if the bus is articulated and zero otherwise.
After TSP date	A dummy variable equaling one if the if the data used for this trip segment were collected after the use of TSP equipped buses along Saint-Michel corridor on September 1st, 2010.
TSP buses	A dummy variable equaling one if the bus is TSP equipped and zero otherwise.
Segment 1	A dummy variable equaling one if the trip occurred between Fleury and Emile-Journault bus stops in either north or south directions (extending for 1820 metres on average) and zero otherwise.
Segment 2	A dummy variable equaling one if the trip occurred between Emile-Journault and Villeray bus stops for either north or south directions (extending for 1912 metres on average) and zero otherwise.
Segment 3	A dummy variable equaling one if the trip occurred between Villeray and

Variable Name	Description
	Beaubien bus stops either for north or south directions (extending for 1554 metres on average) and zero otherwise.
Segment 4	A dummy variable equaling one if the trip occurred between Beaubien and Saint-Joseph bus stops either for north or south directions (extending for 1530 metres on average) and zero otherwise.
CV running time (%)	The coefficient of variation in percentage of running time per trip segment
CV running time deviation (%)	The coefficient of variation of running time deviation in percentage.
CV actual stops (%)	The coefficient of variation of the total number of actual stops made per trip segment in percentage.
CV passenger activity (%)	The coefficient of variation of the sum of passenger activity per trip segment in percentage.
CV articulated passenger activity (%)	The coefficient of variation of the sum of passenger activity on an articulated bus per trip segment in percentage.
CV precip. (%)	The coefficient of variation of the average rainfall measured on a day per trip segment in percentage.
CV snow (%)	The coefficient of variation of the snow precipitation that took place per trip segment in percentage.
CV delay at the start (%)	The coefficient of variation of the delay at the start of a trip segment in percentage.

4.5 ANALYSIS

4.5.1 Descriptive Statistics

Table 4.2 presents summary statistics for the variables used in this study at disaggregated trip segments and at aggregated grouped trip segment levels. For Route 467, the average trip segment’s running time is 382 seconds (6.36 minutes) with standard deviation of 75 seconds, while the average for Route 67 is 418 seconds (6.96 minutes) with standard deviation of 81 seconds. This indicates that route 467 is faster than route 67 with less variation in travel time. The running time deviation percentage average for Route 467 is 100.1%, with standard deviation of 22.8%. Meanwhile, for Route 67, the average running time deviation is 102.3%, with standard deviation of 18.4%. This indicates that on average the actual running time for Route 467 is slightly longer than the scheduled running time by 0.1%, while for Route 67 it is longer by 2.3%.

For route 467 the average coefficient of variation of running time per grouped trip segment is 15.5%, while for Route 67 the variation from the average is 15%. This indicates that while Route 467 is much faster than Route 67, it has more variation in running time relative to the running time mean value. Furthermore, the coefficient of variation of running time deviation for Route 467 is 16.3%, while for Route 67 the average is 15.4%. This indicates more variation in delays for Route 467 than for Route 67. Nevertheless, in order to understand how every strategy implemented by the STM along the corridor affects buses' running time, running time variation and deviation from the schedules at the segment level, four statistical models are presented in the following section.

Table 4.2: Descriptive statistics

Variable	**All data**		**Route 67**		**Route 467**	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Segment running time (seconds)	408.8	81.4	418.3	81.6	382.8	75.0
Segment run time deviation (%)	101.7	19.7	102.3	18.4	100.1	22.8
Segment scheduled running time	406.0	62.4	411.2	54.9	391.9	77.7
Segment passenger activity	32.5	18.7	33.7	18.5	29.3	19.0
Articulated rear door activity	0.7	2.5	0.0	0.0	2.8	4.3
Actual stops made	5.0	1.7	5.8	1.3	2.9	0.3
Northbound	0.5	0.5	0.5	0.5	0.6	0.5
Southbound	0.5	0.5	0.5	0.5	0.4	0.5
Route 467	0.3	0.3	0.0	0.0	1.0	0.0
Route 67	0.7	0.3	1.0	0.0	0.0	0.0
Delay at start (s)	54.3	123.2	54.9	124.5	52.8	119.5
Delay at end (s)	57.1	143.1	62.0	144.9	43.7	136.9
Distance (metre)	1704.3	165.4	1704.5	165.5	1703.6	165.2
Speed (KM)	15.5	2.9	15.1	2.7	16.5	3.2
Precip (mm)	2.9	6.5	2.9	6.2	3.1	7.3
Snow (cm)	3.2	7.0	3.5	7.4	2.4	5.5
Initial situation	0.2	0.4	0.2	0.4	0.0	0.0
Smart card start	0.8	0.4	0.8	0.4	1.0	0.0
Smart card by the end of 2008	0.7	0.5	0.6	0.5	1.0	0.0
Reserved lane	0.2	0.4	0.1	0.3	0.3	0.5
After articulated buses date	0.4	0.5	0.3	0.5	0.7	0.5
Articulated buses	0.2	0.4	0.0	0.0	0.6	0.5
After TSP date	0.2	0.4	0.2	0.4	0.3	0.5
TSP buses	0.1	0.3	0.0	0.0	0.3	0.4
Number of cases	**255,000**		**186,862**		**68,138**	
CV running time (%)	15.2	2.1	15.0	1.8	15.5	2.4
CV running time deviation (%)	15.9	2.6	15.4	2.1	16.3	3.0
CV passenger activity (%)	47.7	7.3	44.7	4.8	50.4	8.0
CV articulated passenger activity (%)	11.6	15.7	0.0	0.0	21.7	18.2
CV actual stops (%)	14.9	6.1	19.5	4.2	10.7	4.2
CV precip. (%)	220.6	24.6	212.7	18.2	227.6	27.4
CV snow (%)	231.7	111.9	229.9	72.9	233.2	138.1
CV delay at the start (%)	214.5	1014	318.9	897	120.2	1103.9
CV delay at the end (%)	816.7	9548	1484	13752	212.7	1478.6
CV speed (%)	15.2	2.0	15.0	1.7	15.4	2.2
Number of cases	**478**		**227**		**251**	

4.5.2 Running Time and Running Time Deviation Models

Two linear regression models are developed for the disaggregated trip segments using running time in seconds and running time deviation by percentage as the dependent variables. Table 4.3 presents the results of these models. The first model, which is the segment running time model, contains 255,000 trip segments and explains 47% of the variation in running time. As expected, among the strategies introduced by STM, the implementation of limited-stop bus service, exclusive bus lane and TSP decrease running time. In contrast, the implementation of smart card systems and use of articulated buses increase running time. Furthermore, the presence of articulated buses along Route 467 led to an increase in running time for all buses using the corridor. Meanwhile the presence of TSP-outfitted buses led to decreases in running time per trip segments for all buses utilizing the corridor. These findings are consistent with earlier research and the previous chapter (Diab & El-Geneidy, 2012; El-Geneidy & Surprenant-Legault, 2010; Surprenant-Legault & El-Geneidy, 2011).

The use of articulated buses have a mixed effect on running time, increasing it due to bus acceleration and manoeuvring within traffic, while decreasing it due to the third door passenger activity (El-Geneidy et al., 2011). Therefore, while total passenger activity from all buses doors increases running time by 1.62 seconds, the use of articulated buses third door decreases the average running time by 3.17 seconds per passenger along a trip segment, indicating a 1.55 seconds time savings for each passenger using the third door. Furthermore, since the average of articulated buses rear door use is 2.8 passengers (as indicated by the summary statistics), the total time savings due to the use of articulated buses third door is 8.8 seconds. Accordingly, the operation of an articulated bus will increase running time by 13 seconds at the segment level.

Each millimetre of rainfall and each centimetre of snow increase bus running time delay by 0.1 and 0.4 seconds, respectively. Furthermore, if the bus is late at the first stop, running time is expected to be faster by 0.07 seconds for every second of delay. This indicates a recovery of 7% against the delay by drivers during the trip segment, since drivers who start late compared to schedules often attempt to compensate for the delay (El-Geneidy et al., 2011; Surprenant-Legault & El-Geneidy, 2011; Tétreault & El-Geneidy, 2010). Compared to midday trips, the afternoon peak increases the running time by 15 seconds, while the morning peak, night time, early morning and midnight time decrease the running time by 8.2, 22.9, and 48.2 seconds. Finally, segment one, three and four are slower by 42, 73, and 92 seconds respectively compared to segment two. This difference between segments is related to the dissimilarity in distance, built environment, and network characteristics.

The second model is running time deviation (%), which represents the actual running time per trip segment divided by the scheduled running time, multiplied by one hundred. This model is used to help in understanding the factors affecting running time deviation from schedule. The model contains 255,000 records and explains 21% of the variation in the running time deviation from schedule. This proportion of explained variance is relatively high and comparable to previous running time deviation models seen in the literature (El-Geneidy et al., 2011). The running time deviation (%) model is generated to understand the quality of the schedules and their relation to actual running time. Generally, it is expected that factors affecting running time deviation should have the same sign and magnitude as the previous model if schedules are adjusted correctly to address the improvement on the ground. Nevertheless, the inconsistency between the two models could be interpreted in terms of adjustments needed to the schedule due to a specific independent variable. Furthermore, the F-Test results, not only for this model but for all four models, show that the F significance is almost equal to zero. Therefore, I reject the null hypothesis with extremely high confidence (above 99.99%) and I conclude that the independent variables as a set have a relationship with the dependent variable.

As seen in table 4.3, in the second model every stop made is expected to deviate from running time schedule by 3.5%. In addition, the average of the actual stops made by a bus along Route 467 and 67 segments are 3 and 6 stops respectively, so that would mean deviations of 10% and 20% from the schedules are expected. Each additional passenger boarding or alighting the bus along the segment deviates the actual running time from schedules by 0.31%, while passenger activity from articulated buses' third door deviates running time by 0.67%. This in part may be a result of the overestimated time savings that was expected by schedulers for the use of the third door on articulated buses. With regard to meteorological factors, for every millimetre of rainfall and centimetre of snow, deviation will increase by 0.02% and 0.1% seconds, respectively. For each second of delay at the first stop along the studied segments, running time deviation decreases by 0.02%. which is consistent with previous studies (Surprenant-Legault & El-Geneidy, 2011).

Morning peak, evening peak, night, along with midnight and early morning are expected to decrease running time deviation from schedules by 0.7%, 3.3 %, 1.4% and 0.3%, compared to midday trips, respectively. This indicates that midday trips usually deviate more from schedules than those during other time periods. Furthermore, characteristics of the built environment also affect deviation from schedules. Segment number one, three and four decrease deviation from schedules by 6.9%, 0.7% and 1.2%, respectively, compared to segment number two, while maintaining all other variables at their mean values.

The implementation of a smart card fare collection system initially increased running time deviation by 0.8%, and by 3.1% at the end of the implementation period in 2008. This indicates that schedules did not adjust to add the extra amount of time contributed by the introduction of smart cards right away, compared to the situation before (when passengers were using the flash passes). At the segment level, the limited-stop bus service (Route 467) is generally expected to deviate from schedules by 6.4% compared to the regular service (Route

67). This indicates that schedulers at STM did not estimate route 467 running time as accurately as they did for Route 67 buses. Northbound running time deviation is 2.7% less than southbound, which indicates that buses are saving more time while travelling north than is anticipated in the schedules. Buses using reserved lanes are found to have a statistically significant positive effect on running time deviation, decreasing it by 4.4%. This indicates that, on average, buses using reserved lanes are gaining time against their schedules in comparison to other buses.

The presence of articulated buses along the corridor led to a 5.3% increase for all bus running time deviation, while the use of an articulated bus decreases the previous value by 0.9% to 4.4%. By adding the running time deviation due to the use of articulated buses' third door (with an average of 2.8 passengers), the use of articulated buses deviates the actual running time from schedules by 6.6%, while keeping all other variables constant at their mean values. This indicates both that there is a problem in scheduling and that articulated buses have a powerful effect on running time delays as well as unexpected effects on other buses' running time delays. This deviation from schedule can be understood in view of two factors. The first is the high frequency of service along the two routes, with the average headway for Route 467 and 67 being less than 7 minutes during the peak hours. The second is the fact that both routes serve the same passengers at the same stops. Therefore, in many cases buses are directly behind each other, which negatively affect the service. Finally, at the segment level, the presence of TSP-outfitted buses along the corridor increases running time deviation from schedules by 0.5% for all buses along the corridor. While for the TSP equipped buses there was no significant effect on running time deviation.

Table 4.3: Segment running time and segment runtime deviation (%) models

Variable	**Segment running time**		**Running time deviation (%)**	
	Coefficients	t	Coefficients	t
(Constant)	**361.23 *****	**405.12**	**73.43 *****	**279.76**
Actual stops	**10.53 *****	**79.71**	**3.48 *****	**89.57**
Segment passenger activity	**1.62 *****	**183.39**	**0.31 *****	**119.88**
Articulated rear door activity	**-3.17 *****	**-48.87**	**0.36 *****	**18.96**
Precip (mm)	**0.14 *****	**7.82**	**0.02 *****	**4.39**
Snow (cm)	**0.37 *****	**21.05**	**0.12 *****	**23.88**
Route 467	**-12.40 *****	**-20.94**	**6.39 *****	**36.66**
Northbound	**-14.59 *****	**-60.17**	**-2.72 *****	**-38.16**
Delay at the start (s)	**-0.07 *****	**-72.65**	**-0.02 *****	**-71.50**
AM Peak	**-8.22 *****	**-23.66**	**-0.76 *****	**-7.39**
PM Peak	**15.10 *****	**43.71**	**-3.36 *****	**-33.00**
Night	**-22.97 *****	**-64.75**	**-1.45 *****	**-13.86**
Midnight and early morning	**-48.21 *****	**-90.22**	**-0.27 ***	**-1.72**
Smart card start	**3.14 *****	**7.41**	**0.83 *****	**6.61**
Smart card by the end of 2008	**12.96 *****	**30.57**	**3.10 *****	**24.88**
Reserved lane	**-11.43 *****	**-29.58**	**-4.37 *****	**-38.45**
After articulated buses date	**9.10 *****	**22.37**	**5.33 *****	**44.52**
Articulated buses	**12.97 *****	**19.24**	**-0.90 *****	**-4.52**
After TSP date	**-1.37 ****	**-3.62**	**0.51 *****	**4.59**
TSP buses	**-1.40 *****	**-2.40**	-0.05	-0.29
Segment 1	**-41.64 *****	**-122.65**	**-6.98 *****	**-69.87**
Segment 3	**-72.60 *****	**-175.44**	**-0.67 *****	**-5.51**
Segment 4	**-91.67 *****	**-264.93**	**-1.29 *****	**-12.69**
N	255,000		255,000	
R^2	0.47		0.21	
F statistic (22, 254977)	10057.0		3087.3	
F significance (Prob > F)	0.00		0.00	

Bold indicate statistical significance

*** Significant at 99% ** Significant at 95% * Significant at 90%

4.5.3 CV Running Time and CV Running Time Deviation Models

The third and fourth linear regression models are developed for the aggregated grouped segments. The third model used the CV of running time multiplied by one hundred as the dependent variable, while the fourth model used the CV of running time deviation multiplied by one hundred as the dependent variable. Table 4.4 presents the results of these models. The CV running time model contains the grouped records of 478 trip segments and accounts for 45% of the variation in the running time variation. In this model, variables that have no statistically significant coefficient indicate that they do not positively or negatively affect the running time variation of routes.

The variance in the number of actual stops made has a statistically significant positive effect, increasing running time variation by 0.06% for every 1% increase in the variability of the number of actual stops made along a segment. Therefore, designing segments or routes with fewer stops is generally recommended in order to decrease the running time variation, which is consistent with previous research (El-Geneidy et al., 2011). Every 1% increase in the variability of the total passengers' activity adds 0.04% in running time CV, while keeping all other variables constant at their mean values. In addition, variance in articulated buses' passenger activity has a positive coefficient, increasing the running time variation by 0.05% for every 1% increase in articulated buses passenger activity.

Fluctuation in snow precipitation increases buses running time variation by 0.002% for every 1% increase in snowfall variance, thus decreasing the attractiveness of the service. The running time variability for northbound buses is greater by 0.4% compared to southbound buses. This indicates that while the northbound buses are much faster than the southbound buses (as indicated by the running time model), they experience a higher level of variability in running time, requiring schedulers to pay more attention to this degree of variability in order to improve service reliability. Midnight and early morning trips show less variability than midday trips by 0.6%, indicating that they are faster and have more stable running time over time.

The implementation of a smart card fare collection system at the end of 2008 increased running time variability by 0.7%, due to the growth in the number of smart card users compared to users of traditional flash passes, making the task of minimizing variation along the corridor more difficult for schedulers. While buses that use reserved lanes are faster by 11 seconds (as indicated by the running time model), they experience more variance in travel time by 0.5% compared to buses that do not use reserved lanes. This variance can be related to the no turn on red traffic light policy because private cars often wait in the reserved lanes in order to turn right (Surprenant-Legault & El-Geneidy, 2011).

CV of running time for articulated buses is 2.8% less than for regular busses. However, this value does not account for the true effect of an articulated bus on running time variation. Hence, the model includes a ‘CV articulated passenger activity’ variable which captures the increases in running time variation due to the increase in articulated buses passenger activity coefficient of variation. Therefore, for every 1% increase in articulated buses passenger activity coefficient of variation, the running time variation increases by 0.09%, and since the average articulated buses passenger activity coefficient of variation is 21% (as indicated by the summary statistics), this indicates a total increase in running time variation by 1.9%. Accordingly, operating an articulated bus decreases the running time variation by 0.9%.This indicates that while articulated buses increase running time by 13 seconds per trip segment, they experience less variation in their running time. In other words, articulated buses are slower with low variance in running time compared to regular buses, making their statistics easier to predict.

Segments one, three and four have a positive coefficient, increasing running time variance in comparison with segment number two, by 1.2%, 3.4% and 1.8% respectively. This finding indicates that buses take less running time along these segments with a high level of variance compared to segment number two. While TSP equipped buses have no significant impact on buses running time variation, the presence of TSP buses along the corridor increased all buses running time variation by 0.5%, which means that not all buses benefit equally from the TSP system. This indicates a negative effect of the operation of TSP equipped buses on all buses’ running time variation along the corridor. According to previous research, TSP benefits are not consistent with running time and running time variation

(Kimpel et al., 2005). Therefore, another detailed study is required to investigate the TSP system components and operation in order to maximize its benefits for not only TSP equipped buses, but for all buses using the same corridor.

Finally, while *smart card start, Route 467 and after articulated buses date* variables have a significant coefficient affecting the average running time per trip segments (as indicated by the running time model), they do not show a significant effect on running time variation. This indicates that the influence of these strategies is limited to the mean value of running time changes, with neutral effects on variation. In other words, the variation before and after the implementation of a smart card, the limited-stop bus service (Route 467), and the presence of articulated buses along the corridor is the same.

Table 4.4: CV segment running time and CV segment running time deviation (%) models

Variable	**CV running time (%)**		**CV running time deviation (%)**	
	Coefficients	**t**	**Coefficients**	**t**
(Constant)	**10.354 *****	**9.58**	**9.332 *****	**6.42**
CV actual stops	**0.063 ****	**2.32**	**0.126 *****	**3.43**
CV passenger activity	**0.042 ****	**2.15**	0.037	1.40
CV articulated passenger activity	**0.054 ****	**2.24**	**0.061 ***	**1.86**
CV precip	-0.006	-1.49	-0.003	-0.60
CV snow	**0.002 *****	**2.56**	**0.003 ****	**2.50**
Route 467	0.257	0.75	**1.809 *****	**3.91**
Northbound	**0.444 *****	**2.79**	-0.187	-0.87
CV delay at the start	0.001	1.25	0.001	1.60
AM Peak	-0.189	-0.89	**-0.479 ***	**-1.69**
PM Peak	0.336	1.41	0.480	1.50
Night	-0.292	-1.12	**-0.664 ***	**-1.89**
Midnight and early morning	**-0.561 ***	**-1.68**	-0.205	-0.46
Smart card start	-0.018	-0.04	-0.107	-0.20
Smart card by the end of 2008	**0.670 ****	**1.97**	**1.185 ****	**2.53**
Reserved lane	**0.486 ****	**2.46**	0.198	0.75
After articulated buses date	0.048	0.19	**-0.997 *****	**-2.94**
Articulated buses	**-2.752 ****	**-2.18**	**-3.475 ****	**-2.05**
After TSP date	**0.453 ****	**1.97**	**0.583 ***	**1.89**
TSP buses	0.236	0.87	0.295	0.80
Segment 1	**1.183 *****	**5.58**	**1.716 *****	**6.02**
Segment 3	**3.377 *****	**14.82**	**3.403 *****	**11.11**
Segment 4	**1.178 *****	**5.50**	**1.684 *****	**5.86**
N	478		478	
R^2	0.45		0.35	
F statistic (22, 455)	16.91		11.11	
F significance (Prob > F)	0.00		0.00	

Bold indicates statistical significance

*** Significant at 99% ** Significant at 95% * Significant at 90%

The fourth model is the CV of running time deviation (%). It contains 478 trip segment patterns and explains 35% of the variation in the CV of running time deviation from schedules. In this model, variables that have no significant coefficient reveal that they do not affect the variation in running time deviation from schedules either positively or negatively. The CV of running time deviation (%) model is generated to gain knowledge of the difference between the running time range of variation of trip segments and the permitted level of variation in the schedules. Generally, it is expected that factors affecting CV of the running time deviation should have the same sign and magnitude as the previous model. However, inconsistency between the two models may be connected to the design of schedules and the unanticipated events that schedulers face in relation to service variation.

The variance in the number of actual stops increases the variance in running time deviation from schedules by 0.1% for every additional 1% increase in the variance of the number of actual stops made. Therefore, designing segments with fewer stops is generally recommended in order to decrease the variation in the deviation from schedules. This is consistent with the previous model. The variance in articulated buses' passenger activity has a positive coefficient value. For every 1% increase in variance of articulated buses' passenger activity, the variance of running time deviation from schedules increases by 0.06%. Every 1% increase in snow precipitation variance increases the variance of running time deviation from schedule by 0.003%. AM peak and night trips show less variability in their travel time deviation from the schedules by 0.5 and 0.7%, respectively, compared to midday trips, indicating that these trips are more consistent in their travel times.

At the segment level, the limited-stop bus service (Route 467) shows higher levels of variance on running time deviation from schedule than Route 67 by 1.8%. This demonstrates that Route 467 buses, while they are faster than Route 67 buses by 12.4 seconds per segment (as indicated by the first model), demonstrate a 6.4% higher running time deviation (as indicated by the second model), with a 2% higher range of variance in deviation from schedules. This high variance in the deviation from schedules for Route 467 indicates a scheduling issue that requires further investigation. Furthermore, by the end of 2008, the implementation of smart cards increased the variance of running time deviation from schedules by 1.2%. This indicates unanticipated difficulty in relation to the implementation of smart cards on service variation.

After the introduction of articulated buses along the corridor, the variance in deviation from schedules for all buses decreased by 0.99%. This means that the variance in deviation from schedule has decreased for all buses, so the service provided is currently more reliable over time due to the presence of articulated buses. For articulated buses, the range of running time deviation from schedules decreased by 3.5% to reach 4.5%, indicating more consistency in the amount of deviation from schedules. Nevertheless, subtracting the previous value from articulated buses' passenger activity variance in deviation indicates that the operation of an articulated bus decreases the range of running time deviation from schedules by 2.5%.

After the introduction of a few TSP equipped buses along Route 467, all buses along the corridor suffered from an increase in the variance in running time deviation from schedules by 0.6%. This indicates that, sometimes, the time savings achieved after the introduction of TSP-equipped buses along the corridor diminishes due to the higher level of added variation. For TSP-equipped buses no significant difference was present when compared to other buses. Furthermore, while reserved lanes decrease bus running time by 11 seconds, they increase the range of running time variation by 0.5%. However, this increase in running time variation does not affect deviation from schedules variation. This may be due to the design of schedules which mitigates this range of variation.

4.6 CONCLUSION

Various measures have been implemented by STM along boulevard Saint-Michel between 2007 and 2011. These measures include the implementation of the smart card fare collection system OPUS, limited-stop bus service (Route 467), reserved bus lanes, introduction of articulated buses, and TSP. The main objective of this chapter is to understand the impact of these measures on bus running time variation, while acknowledging that this variation affects the running time deviation from schedules at the segment level. It analyzes archived data obtained from STM’s AVL and APC systems for Route 67 and 467, using four statistical models. The first and second models were for disaggregated trip segments, investigating the effects of the implemented strategies on running time and running time deviation from schedules. The third and fourth models were for the aggregated grouped trip segments level, examining the effects of the implemented strategies on running time variation and on variation in running time deviation from schedule.

At the segment level, the introduction of a smart card fare collection system increased bus running time by 16.1 seconds (or by 3.8% compared to Route 67 initial situation), increased running time deviation from schedule by 3.9%, increased running time variation by 0.7%, and significantly increased variation in running time deviation from schedule by 1.1%. This indicates an unanticipated problem in relation to the implementation of smart cards on service provision and variation that needs to be addressed by adding more recovery time as well as running time to schedules. The articulated buses saw an increase in running time of 13 seconds (3.1%) on average per segment, accompanied by an increase in running time deviation from schedule of 6.6%. Furthermore, articulated buses were subjected to a decrease in running time variation by 0.9% compared to other buses, and a decrease in variation in running time deviation from schedule by 2.5%. This indicates that articulated buses are consistently slower and behind schedule compared to other buses. Therefore, in general, transit agencies planning to use articulated buses are required to provide more running time and less recovery time than for other bus types. Meanwhile, the presence of articulated buses in the corridor had a negative impact on running time for other buses, increasing it by 9 seconds (2.2%) per trip segment, and increased their deviation from schedules by 5.3%. This increase should be stable since the coefficient of variation of running time deviation from schedules has decreased by 0.99%, with no significant effect on running time variation.

Therefore, it is expected that regular buses running parallel to articulated buses will be consistently late, requiring adjustments in schedules.

While the operation of an exclusive bus lane during peak hours saved an average of 11 seconds (2.7%) for buses utilizing these lanes and decreased running time deviation from schedules by 4.3%, these buses experience more variance in their travel time (0.5% more than buses not using these lanes). This can be linked to the effect of the line up of cars in front of the bus, since Montreal has no turn on a red light policy. This can be solved, to a degree, by locating stops on the far side of intersections as well as prohibiting some right turns along the corridor. The TSP-equipped buses are faster than other buses by 1.4 seconds (0.3%) per trip segment compared to other buses after the introduction of TSP. However, these buses have no significant effect on running time deviation from schedule, running time variation, and variation in running time deviation from schedules. Accordingly, the scheduled running time for TSP-equipped buses can be decreased slightly without affecting the variation in service. On the other hand, the presence of TSP-equipped buses along the corridor had an impact on all non-TSP equipped buses: running time declined for all buses by 1.37 seconds (0.3%) per trip segment. However, these non-TSP equipped buses suffered a 0.5% increase in their running time variance, and a 0.6% increase in variation of running time deviations from schedules. The mixing of TSP-equipped and non-TSP equipped buses is not recommended on high frequency routes due to the impact on running time variation, as such variation will cause a decline in the reliability of service and will require additions in recovery time, diminishing running time savings.

At the segment level, the limited-stop bus service (Route 467) is faster by 12.4 seconds (3.0%) with no significant difference in running time variation compared to the regular service (Route 67). However, Route 467 buses exhibit 6.4% higher running time deviation from schedules, as well as 1.8% higher variance in running time deviation from schedules. This indicates that while the use of limited-stop service is recommended due to running time savings and minimal impact on running time variation, schedule revisions are needed to add more recovery time for Route 467, so that it is similar to the amount of recovery time that exists for Route 67. Finally, the results of this research point out some key elements to consider in the formulation of policies for promoting the use of various improvement strategies along high frequency routes:

- This study has shown that use of a smart card fare collection system, in comparison with the use of traditional flash passes, increases bus running time (as indicated also in chapter 3), running time variation and variation of deviation from schedules. This indicates less efficiency and a bus transit service decline in reliability associated with the use of a smart card fare collection system compared to the use of traditional flash passes, which can be related to the type of technology adopted.
- The use of reserved bus lanes, while improving running time significantly, exacerbates running time variation. Therefore, a clear understanding of the location of reserved bus lanes and bus stops is required, particularly in cities that have no turn on red light policy, as in the case of Montreal.
- The use of articulated buses increases running time and running time deviation from schedules, while it improves running time variation and deviation variation, providing more consistent service. In other words, articulated buses are slower with low variance in running time compared to regular buses, making them easier to predict. Therefore, transit agencies planning to use articulated buses in general are required to provide more running time and less recovery time than for other bus types.
- Furthermore, due to the presence of articulated buses in the corridor, regular buses running in parallel are affected. A negative spillover effect was observed in this study, leading to increase in running times and deviation from schedules among regular buses.

However, less variation of deviation from schedules is expected, with no changes in running time variation. Therefore, it is predictable that regular buses running parallel to articulated buses will be consistently late, so adjustments in scheduled running times are recommended if an agency is planning to mix articulated with non-articulated buses in a route, although this is not an optimal action.

- The use of a limited stop bus has a positive (decreasing) effect on running time with no significant effect on running time variation, although it increases running time deviation and variance of deviation from schedules. This indicates a few benefits of using limited stop bus service and signifies a problem in scheduling. Therefore, using limited-stop bus service is recommended, provided special attention is given to designing the schedules.
- The operation of TSP-equipped buses improves running time with no significant effect on running time variation and variation of deviation from schedules, compared to non-TSP equipped buses. On the other hand, TSP-equipped buses had a mixed effect on non-TSP equipped buses. The first is a positive effect leading to running time savings for non-TSP buses. The second is a negative effect increasing other buses' running time variation and deviation variation. Therefore, to avoid such increases in service variation in the future, mixing TSP buses and non-TSP buses is not recommended along high-frequency routes.

Finally, it was not possible to calculate the headway distribution with the current data used in this study since not all STM buses are equipped with APC and AVL systems. Therefore, it is recommended to develop future studies that investigate the effects of these measures on the headway variation using the same methodology.

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5 CHAPTER FIVE: TRANSITORY OPTIMISM: CHANGES IN PASSENGER PERCEPTION FOLLOWING BUS SERVICE IMPROVEMENT OVER TIME

5.1 OVERVIEW OF CHAPTER

Passengers’ perception and satisfaction have been long seen, and used, as important measures of transit service quality and attractiveness. Indeed, understanding the determinants of commuter satisfaction can be helpful to encourage the use of public transport over the use of the private automobile. The literature shows that public transport' users are generally the least satisfied compared to users of other modes (e.g., active transportation and car users) and experience the lowest commute enjoyment. Researchers indicate that satisfaction is generally influenced by factors both external and internal to the individual. External factors come from objective elements of a commute, such as mode, trip cost, duration, distance, and season. Internal factors are based on commuters’ socio demographics, personality, and preferences, as well as many other factors based on social psychology theories. Within this line of research, researchers indicate that new public transport strategies and technologies offer an added psychological value to the customer, and they have the potential to impact users’ satisfaction, and consequently, behaviour. Therefore, along the same line of thought, understating psychological effects of different improvement strategies on users’ perception is needed.

Chapter 3 indicated that users tend to overestimate the savings in their travel time associated with the utilization of various strategies, while in some cases there are almost no actual savings in their travel time. This indicates a positive attitude towards the utilization of improvement strategies that are not only related to time savings. Nevertheless, a more detailed understanding of how these estimated perceptions can change over time is needed, which is covered in this chapter (Chapter 5). This research tries to understand better transit passengers' perception of the implementation of various improvement strategies in bus service over time. The chapter analyzes three surveys of bus user perceptions conducted over a period of three years. It also uses stop-level data collected from the STM's automatic vehicle location (AVL) and automatic passenger count (APC) systems and bus schedules, in Montréal, Canada, to measure the actual changes in service. Descriptive statistics and regression models are used for a better understanding of the differences between perceptions and reality. The implementation of various strategies has a limited impact in the short-term overestimation by users of their waiting time benefits, whereas the implementation had a long-term impact on their travel time overestimation. This chapter can be of interest to marketing and planning departments at transit agencies, because it provides them with new insights into passengers' perception and satisfaction.

5.2 INTRODUCTION

Passengers' perception and satisfaction have been long seen, and used, as important measures of transit service attractiveness. They are generally a reflection of service quality from the passengers' point of view. Further, these measures have been linked to sustaining high levels of ridership. Along one the busiest bus corridors in Montreal, Canada, the Saint Michel corridor, various measures have been implemented over a period of three years in order to improve the service. This corridor, with an average total daily ridership of 43,000 passengers, has received special attention from the Société de transport de Montréal (STM), the transit provider on the island of Montréal. STM started with the implementation of smart card fares collection in April 2009, replacing the traditional flash passes to provide passengers with a more convenient transport experience and payment option (Société de transport de Montréal, 2010). The main goal of this action was to increase passenger satisfaction and to clamp down on ticket fraud (Corinne, 2008). Second, in March 2009, the STM operated a new limited-stop service, Route 467. The express route (Route 467) is overlaid on the local route (Route 67), sharing only 40% of the regular route stops. The introduction of Route 467 led to a decline in Route 67 service frequency (6.1 minutes to 8.2 minutes headway). Since the new service replaced a few trips along the local Route 67, additional trips were still made by the new service (Route 467), leading to an overall increase in combined frequency at stops served by both routes. Routes 67 and 467 are known as part of the "10-min maximum" network in STM, the brand for frequent service on the island of Montreal. Then STM introduced reserved lanes during the peak hours in August of the same year, improving the service efficiency along the corridor. Next, in February 2010, STM introduced articulated buses along Route 467, increasing the level of comfort to existing users by providing more space and seating capacity on buses. Finally, in September of the same year, STM equipped several articulated buses along Route 467 with a transit signal priority (TSP) system, giving these buses priority over other road vehicles at the corridor’s signalized intersections. Figure 5.1 presents a time line of the strategies implemented by STM along the studied routes between January 2007 and June 2013.

The goal of this chapter is to better understand the change in users’ perception over time in regard to their wait and travel times following the implementation of the measures as described. Chapter Three revealed that passengers did overestimate their travel time saving in the short term after 1 year of the implementation of the previous set of measures, even though there was a minor actual saving in their travel time. However, this information presented only one important part of the truth, since transit agencies are interested not only in making users satisfied at one point of their travel time, but also in keeping users pleased over time with the kind of service being provided. Furthermore, since each strategy implemented along the corridor began at a different point in time, this temporal difference offers a unique opportunity to understand the impact of various strategies on riders' perception.

This study employs three short passenger surveys conducted along the bus corridor to understand the short-, medium-, and long-term changes in passengers' perception and satisfaction (see Figure 5.1). These surveys are used in comparison with the actual operational data collected from STM's automated vehicle location (AVL) and automatic passenger count (APC) systems for Routes 67 and 467 to understand the actual changes in service. "Short term" is defined as 1 year after STM's measures, while the medium and long terms are defined as after 2 and 3 years, respectively. During the survey collections, in September 2011, STM introduced incrementally articulated buses along Route 67, offering more space and seating capacity on buses. The chapter begins with a literature review on passenger waiting and travel times perception, followed by an explanation of the surveys and the methodology used to prepare and analyze the data. Finally, the results of the statistical analysis are discussed. The paper wraps up with some main conclusions and their policy implications for transit planners and operators.

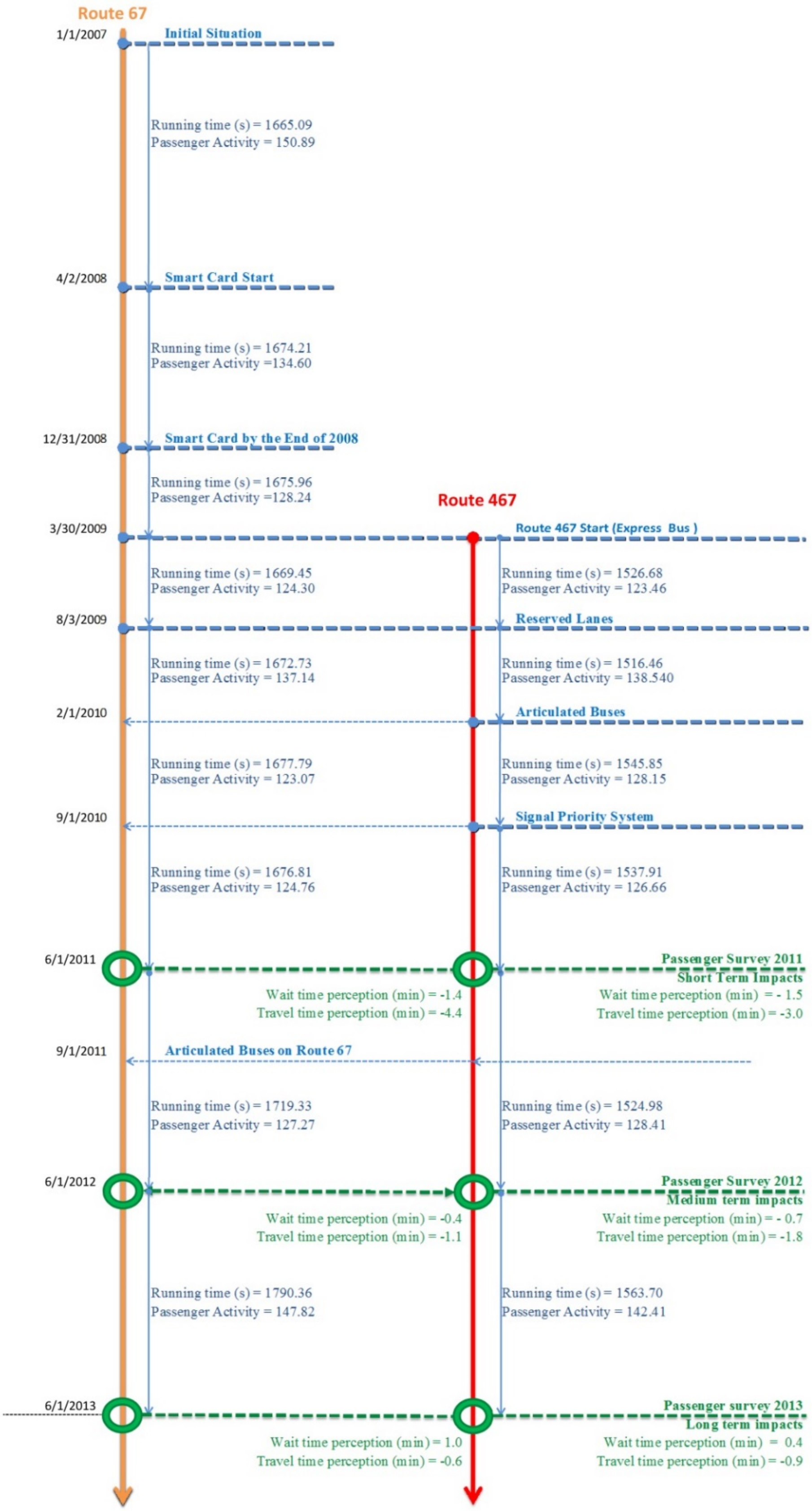

Figure 5.1: Timeline of surveys and changes done to bus service

5.3 LITERATURE REVIEW

Reducing car use and increasing that of public transit is a big challenge. Therefore, increasing investment in various service improvement strategies is becoming more popular in bus public transit, to provide passengers with an attractive service. Thus, it is essential to understand passengers' perception after experiencing these improvements. Researchers indicate that users' perceived service quality is positively related to satisfaction (Bruwer, 2012; C. Chen, 2008; Jen & Hu, 2003; Petrick, 2004), which has been considered the main driver of consumer loyalty and behaviour (Olsen, 2007). Therefore, researchers have linked good perceived transit quality to continued use of a service (Lai & Chen, 2011). In addition, while transit agencies focus on measuring overall satisfaction, researchers indicate that agencies should use customer satisfaction in conjunction with perceived values to better understand users' intentions and loyalty (Joewono, Santoso, & Ningtyas, 2012). Other researchers found that time costs present an important predictor of behaviour changes (Jen & Hu, 2003; Zeithaml, 1988).

Much literature has developed around how users perceive time during a transit trip (Daskalakis & Stathopoulos, 2008; Dziekan & Vermeulen, 2006; Hess et al., 2004; Mishalani et al., 2006; Psarros et al., 2011). Time perception, an important aspect of human experience, has deep roots in psychological research (Y. Li, 2003). Researchers recognize that passengers have a biased perception of actual physical time (Y. Li, 2003; Z. Li, Hensher, & Rose, 2013; van Exel & Rietveld, 2010). For example, researchers agree on the fact that passengers perceive waiting time differently from the actual time (Daskalakis & Stathopoulos, 2008). Mishalani et al. (2006) used linear regression to investigate the relationship between passengers' perceived and actual waiting times, and they found that passengers overestimated their waiting time by 0.84 minutes. Psarros et al. (2011) revealed that for all trip purposes there appears to be a strong overestimation of waiting time. Others researchers indicate that waiting time perceptions change depending on whether passengers make a conscious decision to wait or whether the wait is imposed on them (Hess et al., 2004; Moreau, 1992). For example, researchers report that passengers overestimate their waiting time by a factor of two compared to the actual waiting time when it is imposed by the transit system (2004).

In regard to travel time perception, researchers indicate that travel time perception influence individuals’ route choice (R. Chen & Mahmassani, 2004) and mode choice (van Exel & Rietveld, 2010). In addition, researchers have highlighted the appropriateness of using perceived values compared to observed attribute values in utility calculations in mode choice models (Wan & Lo, 2005). The Transit Capacity and Quality of Service Manual (2003) indicates that perceived travel time equals actual travel time. In addition, researchers reveal a nonlinear relationship for values that individuals put for travel time when there is a travel time variation (Pinjari & Bhat, 2006). This situation indicates that the cost of travel time variation may be greater than the cost of regular travel time (C. Chen et al., 2003; Perk et al., 2008). Further suggested is that travel time variation greatly affects decision making and daily time planning processes (Bates et al., 2001; Nam et al., 2005; Noland & Polak, 2002). However, none of the aforementioned studies have focused on understanding the impact of the implementation of various transit improvement strategies on travellers' perception.

Other research focused on measuring users’ perception and satisfaction immediately or at one time point after implementation of a new measure or route (IBI GROUP, 2003). For instance, in a before-and-after survey in Chicago after implementation of a limited stop service running parallel to a bus route, users indicated a high satisfaction level in many areas, including overall satisfaction, running time, and waiting time, at both the regular and the limited stop service routes (Conlon et al., 2001). A survey in Vancouver, after implementation of new bus rapid transit, indicated a strong satisfaction by passengers with the service (IBI GROUP, 2003). Similar findings were found after a bus rapid transit service implementation in Honolulu (Cham et al., 2006). Another study focused on users' travel time perception, indicating that users overestimate their perceived benefits after implementation of new a limited stop service (El-Geneidy & Surprenant-Legault, 2010). However, in my knowledge, none of these studies have understood how these estimated perceptions can change over time. Only one recent study has investigated the effects of the introduction of real-time information on people' waiting time perception changes over time, using surveys 1 month before, 3 months and 16 months after the system implementation. The study revealed that passengers' waiting time perception decreased after the implementation by 1.30 min without their reporting any actual improvement in service, with no significant change in perception in the long term (Dziekan & Vermeulen, 2006).

Further investigation is required to understand transit passengers' changes in waiting and travel time perception of bus service over time following the implementation of improvement strategies. This is a policy-relevant issue, since agencies should understand the quantitative effects of their policy and implemented strategies not only on their performance, but also on passenger perception. The impact of STM-implemented strategies on bus running time and its variation are well documented in the literature (Diab & El-Geneidy, 2012, 2013). The availability and the accuracy of AVL/APC data offer a good opportunity to study changes in passenger perceptions while controlling for the actual changes in service. The use of archived AVL/APC data is common in the transit literature to understand the changes in bus running time and its variation, dwell time, and on-time performance (Diab & El-Geneidy, 2013; Dueker et al., 2004; Kimpel, 2001).

5.4 METHODOLOGY

The objective of this analysis is to understand the temporal changes in passengers' perception pertaining to their waiting and travel times following the implementation of improvement measures. Data used in the analysis come from three short field surveys. These surveys are meant to capture the short-, medium-, and long-term changes in passengers' perception. Routes 67 and 467 run for approximately 9.4 km (5.8 mi) along the eastern side of Montreal's central business district area and connect two metro stations. The routes share Boulevard Saint-Michel, which has three traffic lanes in each direction. There have been no significant changes in the built environment of the corridor during the past 7 years.

The surveys were carried out from May to June of 2011, 2012, and 2013 on regular weekdays between 7:00 a.m. and 10:30 a.m., and between 2:00 p.m. and 6:30 p.m., to cover both morning and afternoon commuting periods, while isolating the seasonal impact of weather on users' perception. The surveys were done at the southern direction stops during the morning peak to capture the opinion of travellers heading toward the Montreal downtown area, and at the northern direction stops during the afternoon peak to capture travellers returning home. During the surveys, weather conditions were normal, with no major events affecting the typical delivered bus and metro service.

The surveys were self-administered, and each survey team consisted of at least two surveyors at each stop. They handed out surveys and answered any questions that passengers might have had. Surveyed passengers were chosen randomly from the bus waiting lines, or based on who arrived first at stops. Over 90% of the distributed surveys were filled by the passengers in the three waves of surveys. The surveyed bus stops were selected mainly according to the highest number of boarding passengers for both routes covering the main streams of passengers' flow. A total of five northbound stops and six southbound stops on average were used during the surveys, and most of the stops are served by both routes.

The questionnaire was one page long, and included French and English versions (Appendix 1 and 2). Passengers were asked to indicate which bus route (67 or 467) they use most often, and to report when they started using this route. They were also asked to report how often they use this route, by selecting one of three options: *1 day a week or less*, *2 to 4 days a week*, or *5 days a week or more*. Then, respondents were asked if they changed their usual stop to another stop in order to use the 467 express service, selecting one of three options: *no, yes,* and *I am new user of the 467 service.* Next, riders were required to report if they see a difference in their waiting time now compared with when they started using this route. Three options (or checkboxes) were given: a) *yes, longer by …minute(s),* b) *no change*, and c) *yes, shorter by … minute(s).* A similar question was asked for travel time. The surveys also requested that riders identify their alighting stop along the route and report their age and gender. In the medium- and long-term surveys, another question was added to understand riders' level of satisfaction with their overall trip, waiting and travel times using rating systems (1 being unsatisfied to 5 being satisfied). In total, about 1,040 survey responses were collected during the three surveys.

More than 4 million individual stop observations were collected from STM's AVL/APC archival data between January 1, 2007, and May 1, 2013, for both routes. The AVL/APC stop-level observations include bus arrival, departure, and schedule times, and information about passenger activity and load, and bus type. Because the purpose of this paper is to understand the change of passengers' waiting and travel time perception over time, stop-by-stop travel time, bus load at stops, and delay at each stop were calculated. Delay was calculated as bus departure time minus scheduled time. Then, this data set was aggregated according to the implemented strategy time or the year of survey period, route number, and direction. The following survey year periods were calculated: Year 2011 survey period from after TSP implementation to June 2011; Year 2012 survey from July 2011 to June 2012; and finally Year 2013 survey from July 2012 to the end of the study time line.

For each surveyed passenger, the actual change in waiting time and travel time was matched to this data set. For each user, the actual travel time change was considered as the difference between the average travel time and its standard deviation during the survey time compared with when the user started using the service. Similarly, the actual waiting time change was calculated as the difference between half of the scheduled headway and average delay at each user's boarding stop. While Route 67 average headway increased after introduction of Route 467, some of the Route 67 passengers have experienced improvements in headways compared with when they started using the service after implementation of Route 467 along the corridor.

This research uses descriptive statistics and two statistical models based on the survey data to capture and isolate the change in passengers' perception over time. Several t-tests are employed to understand the changes in passengers' estimated perceptions and to compare estimated perceptions with actual waiting and travel time changes. Then, two statistical models are generated to understand overestimation of passengers' waiting and travel times. Table 5.1 includes a detailed description of the variables incorporated in the statistical analysis. Other variables were tested but were eliminated from the study because of their nonsignificance, such as age, gender, change in seating capacity (%), and time of the day.

The key variables in these models are *Year 2011 survey* and *Year 2012 survey*, dummy variables that will distinguish the short- and medium-term impacts of the STM's implemented strategies on respondents' perception compared with the long-term impact survey (conducted in the 2013 year period), respectively. These variables will capture the change in passengers' perception over time. A positive value indicates an increase in the overall perceived waiting and travel time saving compared with that of the long-term survey, while a negative value indicates a decline in perceived time saving.

In addition, various dummy variables were included to control the impact of different improvement strategies. A dummy, *After Articulated Buses*, distinguishes the users that started using the service after articulated buses were implemented and before the TSP. In other words, it distinguishes travellers who witnessed only the TSP implementation. A second dummy variable, *After Reserved Lanes*, distinguishes the passengers who started using the service after implementation of the reserved lane and witnessed the introduction of articulated buses and the TSP system. A third dummy variable, *After Route 467*, characterizes travellers who started using the service after implementation of the express service and saw the use of reserved lanes, articulated buses, and TSP. Finally, the fourth variable, After smart cards, differentiates passengers who started using the service after the introduction of smart cards, while the fifth variable, *initial situation*, distinguishes passengers who started using the service before any STM measures.

The dependent variable in the first model is the difference in estimated waiting time saving. It is meant to capture the overall impact of STM's strategies on users' estimated travel time saving changes over time. The model contains the variable of *waiting time change* to control the actual changes in passengers' waiting time service. The dependent variable in the second model is the difference in estimated travel time saving. It is meant to capture the overall impact of STM's strategies on users' estimated travel time saving changes over time. The model includes three variables to control for the actual changes in service: *travel time change; bus load change (%)*; and *distance (km) * bus load (%)*, an interaction between the change in used bus load and distance in kilometres. Bus load change was calculated at each passenger boarding stop, and it is used to control the impact of increasing the total available capacity of buses along the route, as STM increased the number of articulated buses.

Table 5.1: Description of variables used in the regression models

Variable Name	**Description**
Difference in estimated waiting time (seconds)	Passenger's estimated waiting time saving in seconds minus the actual time change.
Difference in estimated travel time (seconds)	Passenger's estimated travel time saving in seconds minus the actual time change.
Yes, change my stops to use R467	Dummy variable that equals 1 if the rider indicated that she or he changed her or his usual stop to use R467.
Year 2011 Survey	Dummy variable that equals 1 if the survey was conducted between May to June 2011 and zero otherwise. When it is equal to 1, the variable captures the short-term impacts of STM's strategies on perception.
Year 2012 Survey	Dummy variable that equals 1 if the survey was conducted between May to June 2012 and zero otherwise. When it is equal to 1, the variable captures the medium-term impacts of STM's strategies on perception.
After articulated buses	Dummy variable that equals 1 if the surveyed passenger has started using the service after the introduction of articulated buses on boulevard Saint-Michel on February 1, 2010. When it is equal to 1, the variable means that the passenger has only witnessed the implementation of the TSP system.
After Reserved lane	Dummy variable that equals 1 if the surveyed passenger has started using the service after the operation of the reserved bus lanes along the corridor on August 3, 2009. When it is equal to 1, the variable means that the passenger has witnessed the implementation of the articulated buses and the TSP system along the corridor.
After Route 467	Dummy variable that equals 1 if the surveyed passenger has started using the service after the implementation of the express service (Route 467) on March 30, 2009. When it is equal to 1, the variable means that the passenger has witnessed the implementation of the reserved lanes, articulated buses, and the TSP system along the corridor.
After smart cards	Dummy variable that equals 1 if the surveyed passenger has started using the service after the introduction of a smart card payment system (named OPUS) on April 1, 2008. When it is equal to 1, the variable means that the passenger has witnessed the implementation of the Route 467, reserved lanes, articulated buses, and the TSP system along the corridor.
Initial situation	Dummy variable that equals 1 if the surveyed passenger has started using the service before any of the strategies implementation. When it is equal to 1, the variable means that the passenger has witnessed the implementation of all measures.
Waiting time change (sec)	Actual difference in passenger waiting time in seconds between when the survey was collected period and when she or he started using the service.
Travel time change (sec)	Actual difference in passenger travel time in seconds between when the survey was collected period and when she or he started using the service.
Bus load change (%)	Difference in the occupied bus load percentages between the period when the survey was collected and when the passenger started using the service, at her or his boarding stop.
Distance (km) * load change (%)	Interaction variable between passengers' traveled distance in kilometres and the change in bus load percentage.

5.5 GENERAL DESCRIPTION OF SURVEYS ANSWERS

Table 5.2 presents a general summary of the surveys’ respondents. A total of 354, 373, and 310 surveys were collected in 2011, 2012, and 2013, respectively. The table shows the percentage of passenger according to when they started to use the service and which route they use most often, and the percentage of passengers according to their waiting and travel times perception. In addition, the table shows the respondents' gender and average age.

Table 5.2: General characteristics of surveys’ respondents

	Year 2011 survey		**Year 2012 survey**		**Year 2013 survey**		**Total**	
	N	%	N	%	N	%		
Route								
Route 467	183	52%	159	43%	138	45%	480	46%
Route 67	104	29%	144	39%	123	40%	371	36%
Route 67 & 467	67	19%	68	18%	49	16%	184	18%
Frequency of use								
5 days a week or more	224	63%	251	67%	216	70%	691	67%
2 to 4 days a week	91	26%	89	24%	72	23%	252	24%
1 day a week or less	39	11%	33	9%	21	7%	93	9%
Change your stop to use 467 service								
No	223	63%	222	60%	215	69%	660	64%
Yes	103	29%	101	27%	87	28%	291	28%
I am a new user of the 467 service	10	3%	26	7%	8	3%	44	4%
Start using the service period								
Initial situation	99	28%	119	32%	89	29%	307	30%
After smart cards	33	9%	15	4%	17	5%	65	6%
After Route 467	88	25%	45	12%	38	12%	171	16%
After reserved lanes	17	5%	44	12%	32	10%	93	9%
After articulated buses	57	16%	39	10%	14	5%	110	11%
During the surveys collection	60	17%	111	30%	120	39%	291	28%
Waiting time perception								
Decrease in time	133	38%	122	33%	70	23%	325	31%
Increase in time	38	11%	55	15%	77	25%	170	16%
No change	179	51%	189	51%	163	53%	531	51%
Travel time perception								
Decrease in time	184	52%	123	33%	91	29%	398	38%
Increase in time	24	7%	27	7%	31	10%	82	8%
No change	142	40%	218	58%	188	61%	548	53%
Gender								
Female	204	58%	221	59%	186	60%	611	59%
Male	150	42%	145	39%	124	40%	419	40%
Age								
Age 18 -30	109	31%	116	31%	95	31%	320	31%
Age 31-45	78	22%	95	25%	100	32%	273	26%
Age 46-65	71	20%	69	18%	80	26%	220	21%
Age > 65	15	4%	19	5%	18	6%	52	5%
Count of cases	**354**	**5.2%***	**373**	**5.1%***	**310**	**5.5%***	**1037**	

*The confidence interval (also called margin of error) at the 95% confidence level

5.6 ANALYSIS - RESPONDENTS’ PERCEIVED TIME CHANGES AND SATISFACTION

Several t-tests were conducted to test the impact of the different measures on estimated waiting and travel time changes. Table 5.3 shows the statistical results for the perceived changes: means, standard deviations, and significance levels. In this analysis, included were only passengers using Route 67 or Route 467 who provided a time value or who indicated that there was no change in their waiting and travel times. This analysis helps in understanding the change in the mean value of perceived benefits along the studied bus routes.

As seen in Table 5.3, for Route 67, the average estimated waiting time saving in the short-term survey (2011) was 1.4 minutes. This average decreased to 0.4 minutes in the medium-term survey (2012). In the long-term survey (2013), passengers, on average, perceived an increase in their waiting time by 1.1 minutes. There was no significant difference in means between the short- and medium-term surveys, but there was a significant difference between the medium- and long-term surveys, indicating that long-term perception was much lower than for the previous years. A similar trend is noticeable for Route 467: the average perceived waiting time saving in the short-term survey was 1.6 minutes, decreasing to 0.7 and -0.4 minutes in the medium- and long-term surveys, respectively.

In regard to travel time perception for Route 67, the average perceived travel time saving in the short-term survey was 4.4 minutes, decreasing to 1.1 and 0.6 minutes in the medium- and long-term surveys, respectively. There was a significant difference in means between the short- and medium-term surveys, while no significant difference was found between the medium- and long-term surveys, indicating that short-term perception is different from that of other years. For Route 467, similar changes in the significance and values of passengers’ perceived travel time throughout the surveys can be noticed. The average perceived travel time saving in the short-term survey was 3.0 minutes, decreasing to 1.8 and 0.9 minutes in the medium- and long-term surveys, respectively. To better understand the previous findings, the next section compares perceptions with actual changes by using t-tests.

For benchmarking purposes, overall satisfaction of passengers and passengers’ satisfaction with travel and waiting times were collected. Overall satisfaction pertains to a holistic evaluation after a service delivery experience (Lai & Chen, 2011; Petrick, 2004). Both routes’ percentages of overall trip satisfaction are comparable with STM’s general reported overall trip satisfaction with bus service in 2012, about 82% (Société de Transport de Montréal, 2013).

Table 5.3: Waiting and travel times perception and satisfaction (t-test)

	Route 67			**Route 467**		
Survey year	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**
Waiting time perception (minutes)						
N	97	126	114	167	137	121
Mean (Std. dev.)	1.4 (4.9)	0.4 (5.8)	-1.1 (5.8)	1.6 (3.9)	0.7 (4.3)	-0.4 (4.0)
Significant level – α*	0.15	**0.00**		0.08	**0.00**	
Travel time perception (minutes)						
N	92	127	112	162	132	126
Mean (Std. dev.)	4.4 (5.9)	1.1 (4.6)	0.6 (3.5)	3.0 (4.3)	1.8 (5.0)	0.9 (5.3)
Significant level - R *, α	**0.00**	0.38		**0.03**	0.17	
Satisfaction (out of 5)						
Overall trip satisfaction						
N	---	136	116	---	154	130
Mean (Std. dev.)		3.9 (0.9)	4.0 (0.9)		4.2 (0.7)	3.9 (0.8)
Significant level - R *, α		0.24			**0.00**	
Waiting time satisfaction						
N	---	136	116	---	155	130
Mean (Std. dev.)		3.7 (0.9)	3.7 (1.0)		3.9 (1.0)	3.6 (1.0)
Significant level - R *, α		0.94			**0.00**	
Travel time satisfaction						
N	---	136	116	---	153	130
Mean (Std. dev.)		3.9 (0.9)	4.1 (0.9)		4.2 (0.8)	4.0 (0.8)
Significant level - R *, α		0.33			**0.03**	

Bold indicate statistical significance
* Significant level of difference in means t-test between consecutive years, e.g. Route 67’ 2011 and 2012 records

5.7 PERCEPTION CHANGE IN RELATION TO THE ACTUAL CHANGE IN SERVICE

For a better understanding of how passengers overestimated their waiting and travel time saving, and how this overestimation changed over time, a paired difference in means *t*-test was used to compare perceptions with the actual waiting and travel time changes for passengers. The analysis in this and the following section was completed for riders who reported their alighting stops and who indicated the right starting period while the service is operated (particularly for Route 467 users). Figure 5.2-A shows the waiting time paired differences, and Figure 5.2-B shows the travel time paired differences.

On Route 467, passengers overestimated their waiting time savings by 1.8 to 3.2 minutes in the short term. This range of estimated time saving dropped in the medium term to be within 0.5 to 2.1 minutes of saving, while there was an improvement in their actual waiting time saving. This demonstrates a negative bias in their answers since there was a slight improvement in the service. The improvement in service may result from increases in the operational quality of TSP system. In the long term, travellers’ overestimated waiting time saving dropped to be within the range of 0.3 to 1.8 minutes. These decreases in perception were positively correlated with decreases in the actual waiting time ($p < .05$), implying a strong relationship between the actual and estimated waiting times.

For Route 67 passengers, there was a trend of decline in perceived waiting time throughout the three periods. Passengers significantly overestimated their waiting time saving within a range of 1.1 to 3.2 minutes, and 0.5 to 2.6 minutes in the short and medium terms, respectively, while the difference between their estimated waiting time saving and the actual changes was not significant in the long term. This result indicates a diminishing trend of waiting time overestimation in the long term. That is understandable, since passengers are more sensitive to their waiting time changes compared with other components of the trip.

In regard to passengers' travel time along Route 467, as seen in Figure 5.2-B, there is a consistent decrease in their overestimated travel time saving over time. In the short term, they overestimated their travel time savings within a range of 2.5 to 4.0 minutes. In the medium term, the range of overestimated time saving dropped to a range of 1.1 to 3.3 minutes saving, although there was a slight positive enhancement in the actual running time. This decline in users' estimated time benefits corresponds to the increase in the bus occupancy rate, indicating that buses are more crowded in the medium and long terms compared with the short term. In the long term, the difference between passenger travel time perception and actual changes was not significant. This insignificance may result from the high level of fluctuations in passengers' travel time overestimation along the route.

For Route 67, passengers overestimated their travel time saving by 3.6 to 6.1 minutes in the short term. This range dropped sharply to the range of 0.7 to 2.6 minutes in the medium term, although there was a minor decline in the actual service travel time. In the long term, travellers overestimated their travel time saving by 0.8 to 2.2 minutes. This result indicates a stabilization in passengers' estimated saving, while there was a decline in the actual service from 0.4 to 1.0 minutes. This result may stem from the increasing bus capacity along the route, and that increased the level of comfort and perception. For an understanding of the change in passengers' perception of their waiting and travel times, two statistical models are generated and reported in the next section.

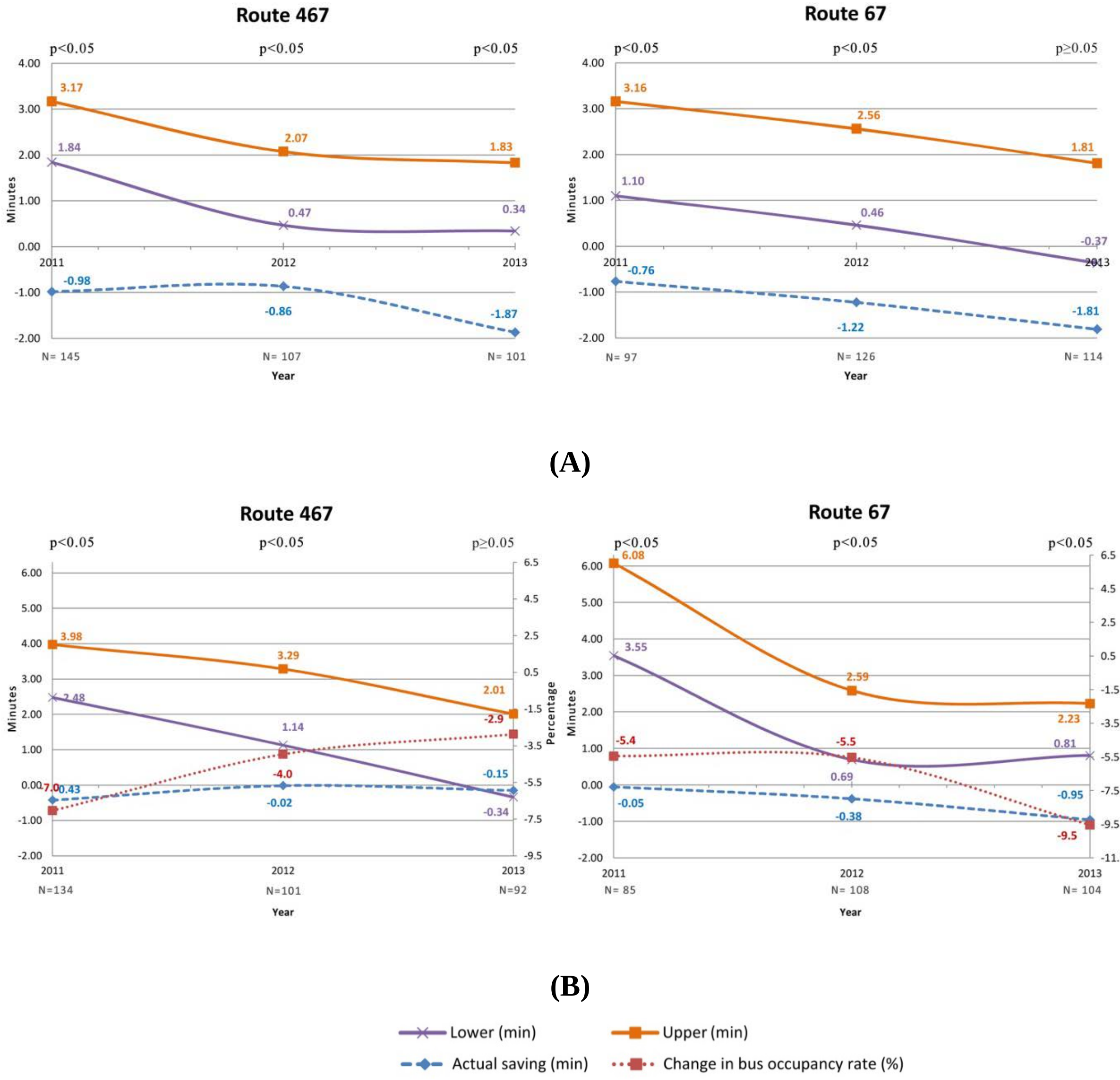

Figure 5.2: A. Users waiting time paired differences and B. Users travel time paired differences

5.8 OVERESTIMATED BENEFITS PERCEPTIONS MODELS

Two linear regression models are developed using the difference in passengers' *perceived* waiting and travel time compared with *actual* change in waiting and travel times as the dependent variable. In these models, included were only passengers who indicated a positive estimation of their waiting and travel times or who saw no change in the service. This was done to understand the difference between users' overestimations over time and to understand the estimated coefficients sign direction. Table 5.4 presents the regression results. The first model, the difference in estimated waiting time savings model, contains 565 records and explains 27% of the variation in the overestimated waiting time. The second model, the difference in estimated travel time savings model, contains 558 records and explains 20% of the variation in the difference between estimated and actual travel time. This proportion of explained variance in both models is comparable with previous models in the literature (Hall, 2001).

Table 5.4: Waiting and travel time perception models

Variable	Difference in estimated waiting time savings (sec)			Difference in estimated travel time savings (sec)		
	Mean	Coefficients	t	Mean	Coefficients	t
(Constant)		7.55	0.71		0.24	0.01
Yes, change stops to use R467	0.26	**28.2***	**1.70**	0.27	**74.9*****	**3.29**
After articulated buses	0.64	4.59	0.17	0.65	-3.48	-0.11
After reserved lanes	0.50	**65.8****	**2.02**	0.51	**94.8****	**1.95**
After Route 467	0.42	1.82	0.06	0.43	**93.2****	**2.03**
After smart cards	0.23	-42.5	-0.81	0.25	**112.2***	**1.70**
Initial situation	0.21	**102.4****	**2.07**	0.22	-101.2	-1.60
Year 2012 survey	0.34	28.8	1.44	0.32	**48.6***	**1.85**
Year 2011 survey	0.37	**58.2*****	**2.52**	0.37	**112.5*****	**4.21**
Route 467	0.53	17.6	0.91	0.51	29.2	1.13
Actual change in wait time (sec)	69.8	**0.97*****	**6.00**			
Actual change in travel time (sec)				22.7	**0.93*****	**3.82**
Bus load change (%)				-5.60	**9.23*****	**2.80**
Distance (km) * load change (%)				-14.9	**-1.91*****	**-2.73**
N	565			558		
R^2	0.27			0.20		
F statistic	(9, 564) 22.65			(12, 545) 11.51		
F significance (Prob > F)	0			0		

Bold indicate statistical significance

*** Significant at 99% ** Significant at 95% * Significant at 90%

As seen in Table 5.4 for the waiting time model, the key policy variable *Year 2012 survey*, accounting for medium-term perception, has a positive coefficient but is not significant compared with long-term impact of STM's strategies on users' perception. This result indicates no significant difference in passengers' perception between the 2 years. In contrast, the variable *Year 2011 survey* has a positive significant coefficient. This coefficient suggests that passengers in the short term after STM's implemented strategies overestimated their time saving by 58 seconds compared with in the long term. The result suggests that implementation of the improvement strategies has a positive impact on the estimation of saving in the short term, but the impact diminishes in the medium and long terms—while controlling for the type of strategy that users witnessed and the actual changes in service.

In regard to the control variables, users who indicated that they changed their usual stop to another stop to use the express 467 service perceived a 28 seconds saving in their waiting time compared with passengers who indicated they did not change their usual stop and with new passengers. This finding suggests that while the users do walk more to use the faster service, they perceive the service more positively. In regard to when the passengers started using the service, those who used the service after the presence of articulated buses and who saw only the introduction of the TSP system did not feel a significant difference in their waiting time compared with passengers who used the service during the survey collection periods (2011, 2012, and 2013). In contrast, passengers who started using the service after the implementation of reserved lanes and who witnessed the implementation of articulated buses perceived 65 seconds more of time saving than the previous group did. One explanation may be that articulated buses offer more bus capacity, thus decreasing the importance of waiting in line. In addition, passengers are less likely to have to wait for a following bus, as happened in some cases when the regular bus was full as a result of the increase in bus load. Thus, this increase in capacity may lead to decreases in passengers' waiting anxiety, which is linked to their overestimation of their actual waiting time (Taylor et al., 2007). Passengers who started using the service after the introduction of the express service and after the use of smart cards did not perceive a significant saving compared with the previous cohort. Passengers who started using the service before the implementation of any strategy indicate perceived waiting time saving of 102 seconds compared with the previous cohorts.

Finally, a one second increase in actual waiting time is expected to increase the difference in passengers’ overestimated time saving compared with the actual one by 1 second. This result may stem from the fact that passengers use homogenous time value (such as 2, 5, and 10 minutes) to report their time saving regardless of the actual change impact. It also suggests that overestimation is not only related to actual changes, but also to other factors associated with strategies.

In regard to the second model of estimated travel time saving, the key policy variables *Year 2012 survey* and *Year 2011 survey* had positive significant coefficients. This indicates that passengers, in the medium term and short term, overestimated their time saving by 49 seconds and 113 seconds more compared with the long term, respectively, while keeping all other variables at their mean values. This suggests that incremental implementation of improvement strategies over longer periods is more appropriate to keep a higher level of perceived trip benefits.

In regard to the control variables, passengers who indicated that they changed their usual stop to use the Route 467 service felt they saved 75 seconds more in their travel time compared with passengers who indicated that they did not change their usual stop and to new users. This suggests self-selection impacts on perception: although these users walk more than other passengers do to use the express service, they perceive their travel time and waiting times more positively.

Passengers who used the service after the implementation of articulated buses along the corridor and saw only the introduction of the TSP system did not feel a significant difference in their travel time compared with passengers who used the service during the survey collection periods. Passengers who started using the service after the operation of reserved lanes and witnessed the introduction of articulated buses perceived a 95 seconds time saving more than the previous group did. Those who started using the service after implementation of Route 467 and before the operation of reserved lanes perceived an additional 93 seconds time saving. Finally, passengers who started using the service before implementation of Route 467 perceived 112 seconds of additional time saving. Passengers who began using the service before any strategy implementation do not significantly differ, in response, from the last group's value. This result suggests that implementing strategies that have a visible, physical component that people can see—such as the articulated buses—has a positive impact on passengers' overestimation of their benefits, in comparison with strategies that do not have a clear physical component, such as the TSP system. Nevertheless, more in-depth study may be useful to identify and prioritize the different features in the studied strategies that have a positive impact on riders' perception.

Every one second increase in the actual travel time is expected to increase the difference between the estimated saving and the actual change by 1 second. Every additional 1% in the bus load is expected to increase the overestimated travel time saving by 9 seconds. However, the model includes a variable of *distance (km)* $*$ *load change (%)*, which captures the combined impacts of passenger-travelled distance and load change on passengers' perceptions. Every one-unit increase in this variable decreases the estimated travel time saving by 1.9 seconds. In other words, this indicates that decreasing bus load is appreciated by passengers who take the bus for longer distances. Further, this indicates a threshold of 4.9 km (by dividing the two variables' coefficients) in which passengers will report a decrease in their travel time estimation that corresponds to increases in buses used load (%), while keeping all other variables at their mean values.

Finally, using the previous two models’ coefficients, it is possible to predict the changes in users’ estimated waiting and travel time saving by conducting a sensitivity analysis while keeping all variables constant at their mean values. In the short term, passengers overestimated their wait time by 131 seconds. This value dropped by 22% in the medium term to reach 101 seconds with no significant difference in the long-term impacts. In regard to travel time perception, in the short term, passengers overestimated their travel time by 224 seconds. This value went down by 29% in the medium term to reach 160 seconds, and by 50% in the long term to reach 112 seconds.

5.9 DISCUSSION AND CONCLUSION

This chapter aimed to understand the change in passengers’ perception of a bus service following the implementation of a set of improvement measures by STM along Boulevard Saint-Michel, in Montreal, Canada. Comparing passengers’ perceptions with the actual changes in service along the bus corridor showed that passengers overestimated their waiting and travel times saving in the short, medium, and long terms. However, there was on average no actual saving in bus running times compared with when they started using the service in most cases. This was kept in mind, and to understand the difference in passengers’ overestimations, two statistical models have been generated, concerning passengers who felt a positive or null change in their waiting and travel times. Findings from these models suggest that in the short term, passengers feel a significant difference in their estimated waiting time saving compared with the long term, while in the medium term, there is no significant difference in perception compared with the long term. This result suggests that implementation of various strategies have only a limited impact in the short term for users’ overestimation of their waiting benefits, and that their overestimation diminishes in the medium and long terms.

In regard to travel time perception, passengers felt a significant positive saving in the short and medium terms compared with the long term. This finding confirms a declining trend of perceived travel time saving over time while controlling for the period when the passenger started using the service and for actual changes in service. It suggests that if an operator wishes to upgrade the quality of its service pertaining to travel time, an incremental implementation of improvement strategies is suggested, to maintain a higher level of passenger perception for a longer period. This higher level of perceived saving would increase passenger satisfaction, and it would retain passengers and ridership despite fluctuations in the quality of the system.

For passengers' overestimation of travel time saving, it is suggested that adopting improvement strategies having a component that passengers can directly witness as having positive tangible impacts may be preferable over slightly enhancing the service quality, in regard to bus speed. In other words, the model suggests that passengers will overestimate their travel time saving more after implementation of a new type of bus than after equipping the buses with a TSP system, for example—unless, perhaps, the TSP system is well-advertised along the corridor. In addition, the model indicates that decreasing the bus load is appreciated by passengers who take the bus for longer distances. Using articulated buses is further associated with a positive impact on passengers' waiting and travel time perception. This may be linked to the presence of a third door, as well as the decrease in users' anxiety of finding a space on the bus while waiting for it. Therefore, transit agencies planning to use articulated buses in general are required to increase their operation efficiency by applying all-door boarding strategies. These strategies may increase boarding speed and also enhance passenger perception and satisfaction. Furthermore, in-depth qualitative study may be useful to identify and prioritize the different features on articulated buses that may have an impact on user's perception.

Finally, this article indicated that passengers who choose to walk more to use the faster service perceive more waiting and travel time saving. Thus, a more detailed study concerning the impacts of other strategies, such as bus stop consolidation, on perception and satisfaction changes over time is recommended, to maximize the benefits of the implementation of various improvement strategies on passengers' perception.

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6 CHAPTER SIX: SUMMARY, DISCUSSION, AND CONCLUSION

6.1 SUMMARY OF CHAPTERS

Many of the most important challenges facing cities and public agencies in the 21st century involve improving transit service to compete with privately owned vehicles. In fact, improving transit service has been promoted by employing various strategies (e.g., articulated buses, bus reserved lanes, transit signal priority systems (TSP), etc.) but with no clear understanding of their actual effect on the quality of service or on people's perceptions. My dissertation has dealt with this challenge by offering a better understanding of passengers' perceptions, transit agencies' actions and the use of improvement strategies. It contributes to knowledge in four key ways:

- It identifies the gaps and overlaps between passengers' and transit agencies' perspectives regarding transit service reliability and the impacts of service improvement strategies, as well as a set of indicators and approaches that capture users' reactions to transportation planning decisions.
- It develops methodologies to deepen understanding of the collective effect of strategies and the synergies between them on the performance of transit systems.
- It develops methodologies to understand the impact of various strategies and their synergies on transit system variation.
- It deepens understanding of how people respond to these strategies and to what extent they overestimate their time savings, and how these estimated savings can change over time.

These contributions were made using mixed methods of research design and a multi-stage approach. The mixed-methods design includes qualitative analysis and several forms of quantitative research. The multi-stage approach is based on the idea that each stage (or chapter) builds on the previous chapters. The empirical studies (Chapters 3, 4, and 5) are based on the first literature review chapter (Chapter 2). In addition, the fourth and the fifth chapters are based on the third chapter's results and methodology. This concluding chapter will first summarize the findings from preceding chapters and then address the policy lessons that could be taken from this research in order to improve public transport planning and decision-making in the future. Finally, the chapter will finish with some thoughts concerning future research.

The overarching finding of this research is that much work is still needed to better understand and ensure that the impact of transit improvement strategies is adequately accounted for in the decision-making process. The methodological advances presented here could be an important step toward a more comprehensive view of how various strategies impact transit service reliability as well as users' perceptions. Better understanding of users' perceptions associated with the implementation of service improvement strategies can address a wide range of societal and environmental goals beyond the movement of people from point A to point B.

As seen in Chapter 2, the overlap between passengers' and transit agencies' perspectives on reliability centres on agreement about its importance to the service provided. There are several key differences between both perspectives in terms of the definition of reliability, the standard viewpoint regarding OTP, and the unaddressed variation issues. A number of studies examined the immediate effects of the implementation of different strategies on users' perceptions, and they generally indicate that passengers tend to perceive the service more positively after the implementation of a new strategy. In this case, transit users tend to be satisfied and significantly overestimate the benefits. This bias may occur because users witness the implementation of such measures, as well as the related time saving that they experience. However, why users overestimate these benefits and how these estimated perceptions change over time are questions rarely raised in the literature.

It is essential to assess to what extent the academic literature provides transit agencies with useful information related to the impacts of various strategies. The impacts of various strategies on run time and dwell time have long been discussed in the literature. However, it appears that less attention has been given to the impact of various strategies on service variation. Furthermore, it is rare to find studies that provide a comprehensive analysis of the impact of implementing a set of strategies on service reliability. Therefore, understanding the synergies and the collective impact of these strategies is much needed. This is particularly relevant to transit agencies' practices, since no transit agency indicated that only one strategy was used to improve their service, and despite the fact that they often employ BRT or BRT-like systems (that combine a few strategies in order to improve the service). This knowledge is important to help transit agencies prioritize one strategy or a set of strategies over others. The limited focus of the existing literature does not match the knowledge requirements of transit agencies, which might be compromising their ability to correctly anticipate the impact of their efforts on the service and on passengers' perception. The results of Chapter two are based on a systematic review method to identify the international literature that covers passenger perspective, while analysing the perspective of transit agencies regarding service reliability and the strategies employed in order to improve it.

The third chapter takes some of the previous chapter's findings and investigates the collective impact of strategies and the synergies between them on transit system running time, while measuring their immediate impact on users' perceptions. It focuses on understanding the impact of service improvement strategies on running time at the route level, which was one of the main goals these strategies were implemented for. The study indicates that strategies have unexpected impact when they are implemented together. For example, articulated buses have a negative spillover effect on other buses, causing delays for other buses in the corridor. Therefore, mixing between articulated buses and regular ones is not recommended in order to avoid such an effect in the future along high frequency routes. Meanwhile, TSP-equipped buses had a positive impact on non-TSP equipped buses, leading to time savings for these buses. On the other hand, users tend to overestimate the savings in their travel time associated with the utilization of the strategies, when in fact there are in some cases almost no actual savings in their travel time. This indicates a positive attitude towards the utilization of improvement strategies that are not only related to time savings.

Chapter 4 provides a detailed methodology to identify the impacts of various strategies and their synergies on transit service variation. In contrast to the previous chapter, the focus of this study is on running time at the bus route segment level of analysis, which relates more to users' experiences. It indicates that the introduction of a smart card fare collection system increased bus running time and service variation compared to the situation before, when traditional flash passes were used. Other analyzed strategies have mixed effects on variation in comparison to the running time changes. The presence of articulated buses in the corridor has an impact on regular buses, increasing running times and deviation from schedules among regular buses. However, less variation of deviation from schedules is expected. Therefore, it is expected that regular buses running parallel to articulated buses will be consistently late. In contrast, TSP-equipped buses had a mixed effect on non-TSP equipped buses running parallel. The first of those is a positive effect leading to running time savings for non-TSP buses. The second is a negative effect increasing other buses' running time variation and deviation variation. Therefore, to avoid such increases in service variation in the future, mixing TSP buses and non-TSP buses is not recommended along high frequency routes. The findings of both chapters (chapter 3 and 4), which are based on the analysis of a large set of operational data, are some of the most robust international results to date that help transit planners and policy makers to better understand the effects of various strategies on different aspects of service variation.

The final empirical work (Chapter 5) built on the finding in Chapter 2 and Chapter 3 related to passengers’ perception of their travel time savings. It explores to what extent passengers overestimate their time savings, and how these estimated perceptions can change over time. In contrast to the third chapter, the focus of this chapter is not only on passengers’ travel time perception, but also on their waiting time perception. The implementation of various strategies had a limited impact on the short-term overestimation by users of their waiting time benefits, whereas the implementation had a long-term impact on their travel time overestimation. Furthermore, the study indicates that some strategies more than others have a positive impact on users’ perceptions, while controlling for the actual changes in service. This chapter's results elaborate on the current literature and current practice that traditionally ignore the range of temporal impacts of strategies and the differences between the effects of strategies on perception. The findings are reached by examining the results of three surveys that were collected over a span of three years following the implementation of a set of strategies. This study provides transit agencies’ marketing and planning departments with important insights regarding passengers’ perception following the implementation of service improvement strategies.

Finally, this research points out the need to improve decision-making by improving measurement tools to include passengers’ perceptions factors. Planners should strive to find indicators that encompass not only the actual changes in the service but also the perceived benefits. These perceived benefits could change according to the type and structure of the implemented improvement strategy. Chapters 3 and 4 of this dissertation show how the collective impact of a set of strategies, and the synergies between strategies, can be measured using actual operational data normally available to modern transit agencies around the world. This will be highlighted in the policy implications section below.

6.2 THEORETICAL AND METHODOLOGICAL CONTRIBUTIONS

A major objective of this research was to identify the gaps and overlaps in passengers' and transit agencies' perspectives regarding transit service reliability and the implementation of service improvements strategies. The methodology used for reviewing the two perspectives simultaneously in an integrated manner provides a new practical addition to the literature, which has traditionally focused on either passengers' or transit agencies' perspectives on service reliability. As a result of this comprehensive approach, several important gaps in understanding have been identified. These gaps can be addressed to enable transit agencies to achieve better service that is positively perceived by passengers

A major contribution of this research is to develop a methodology to deepen our understanding of the collective effect of strategies and the synergies between them on transit system running time and its variation. In contrast to previous research seen in the literature addressing the impact of one or two strategies on the transit service quality, this research provides a comprehensive analysis of the impact of implementing a set of strategies on service reliability. This research indicates that it is important to account for synergies between strategies since they may have unexpected impacts when they are implemented together. This is particularly relevant to transit agencies' practice, since no transit agency indicated using only one strategy to improve their service, often employing BRT or BRT-like systems that combine a few strategies in order to improve the service. It also indicates that several strategies have mixed effects on variation in comparison to the running time changes.

Another important contribution of this research is related to the understanding of how people respond to these strategies, to what extent they overestimate their time savings, and how these estimated perceptions can change over time. This is an important policy-relevant issue, since agencies should not only understand the quantitative effects of their policies and implemented strategies on their performance, but also on passengers' perception. Such knowledge will provide an understanding of the link between passengers' perception and the benefits of using a specific strategy, which may lead to more accurate measures and predictors of behavioural responses.

By measuring the immediate impact of a set of service improvement strategies on passenger's perception, this study was able to indicate that users tend to overestimate the savings in their travel time associated with the utilization of the strategies, while there are almost no actual savings in their travel time in some cases. This indicates a positive attitude towards the utilization of improvement strategies that are not strictly related to actual savings. In addition, the implementation of various strategies has a short-term impact on users' overestimation of their waiting time benefits, while it has a long-term impact on their travel time overestimation. Furthermore, the study indicates that some strategies more than others have a positive impact on users' perceptions, while controlling for the actual changes in service. These findings challenge the literature and current practice, which has traditionally ignored the range of temporal impact of strategies and the differences between the effects of different strategies on users' perception.

A mixed-method and multi-stage research design was used to answer the research questions. It includes quantitative as well as qualitative methods. One of the main contributions of this research is related to utilizing both transit agencies' actual operational data (AVL/APC data) along with transit user perception surveys that require users to quantify the changes in their waiting time and travel time. This allowed the building of accurate models that analyze the changes in passengers' perceptions over time while controlling for the actual changes in the service in terms of travel time, waiting time and service capacity, etc. This methodology provides a better connection between passengers’ perceptions and improvement efforts made by agencies, which could lead to more accurate integration between users’ perceptions and policy making during the service planning and operation process.

6.3 POLICY IMPLICATIONS

Transit agencies implement many strategies in order to provide an attractive transportation service. Planners, policy makers and transportation engineers have to consider multiple goals in order to not only improve the quality of provided service, but also to enrich the quality perceived by users. This will help to ensure the validity of transportation planning decisions in order to achieve the required goals. The work presented here helps to bring these issues to the forefront though a series of qualitative and quantitative studies. I believe that balancing priorities is far from a simple task. However, for planners and policy-makers to begin to address the wider perceived benefits that transportation systems can provide, a deeper understanding of how transportation improvement decisions impact the service quality is absolutely necessary. To this end, the research leads to the following recommendations concerning the use of improvement strategies in order to provide a better service that is perceived positively by users:

- Several differences between transit agencies' and users' perspectives are found that should be taken into consideration, particularly in terms of the definition of reliability, the standard viewpoint regarding on-time performance (OTP), and the unaddressed variation issues.
- Improvement strategies have unexpected impacts on transit operations when they are implemented together along high frequency routes, and this should be taken into consideration in order to improve the service.

- The mixed effect of improvement strategies on service variation in comparison to running time changes has to be acknowledged as an important element to be accounted for while planning for improving transit service reliability.
- Differences between users' travel time and waiting time perceptions of the benefits created by improvement strategies should be expected and understood in transit planning processes.
- Measurements of the impact of service improvements strategies on users' perception should be done over time.
- An incremental implementation of improvement strategies is recommended to maintain a higher level of passenger perception for a longer period, despite system quality fluctuations.
- Some improvement strategies more than others have a positive impact on users' perceptions that is not related to the actual changes in service, which should be taken into consideration.
- Low occupied buses should be maintained for longer distance routes.

These recommendations capture elements of utilizing various strategies in order to improve the service in an easily-understood manner. This research explores how some of these elements can be measured and analyzed using data and skills that should be available to all modern transit agencies around the world.

6.4 FUTURE RESEARCH

While this research is considered a significant step towards a better understanding of the impact of service improvement strategies on service reliability and passengers' perception, there are still a number of issues that need to be addressed which are not directly covered by the research questions. This will be elaborated on here.

The understanding of transit agencies' perspective focused only on analysing large North American transit agencies' perspectives regarding service reliability. This geographic scope could be expanded to explore how transit agencies perceive transit service reliability issues internationally. How and to what extent do they measure riders' perceptions of service reliability, and what reliability indicators and service improvement strategies do they use?

In the second chapter several gaps in the literature have been identified that need further exploration. Particular attention should be given to one of the main aspects of passengers' view relating to the reliability of transit service, which is their response to waiting time variation due to bus delays. That is, future work using innovative methods and smart card fare collection data could provide important insights about how people perceive waiting time delays and their variation and how they act during that experience.

This study focused on investigating the impact of various strategies on bus service running time and its variation. However, more detailed studies to expand on this work are recommended in order to understand the impact of various strategies and the synergies between strategies on transit service headway adherence. It was not possible to calculate the headway distribution with the current data used in this study since not all STM buses are equipped with APC and AVL systems. Indeed, much could be learned from taking a similar approach and methodology to analyze headway variation. Therefore, it is recommended to develop future studies to investigate the effect of the above measures on transit service headway variation.

This research indicated that some strategies more than others have a positive impact on users' perceptions. Therefore, in-depth qualitative studies may be useful to explore more explicitly the different features of strategies that may have an impact on users' perception. This would help to better identify and prioritize the different features that would improve transit users' perceptions. Furthermore, since the empirical work presented here was conducted in Montreal, Canada, and because the city has a unique geography, climate and transit system, much could be learned from taking a similar approach in other cities.

Finally, this research focused on the impact of several strategies, including: using smart card fare collection, introducing limited-stop bus service, implementing reserved bus lanes, using articulated buses, and implementing transit signal priority (TSP). Thus, more detailed studies, using a similar methodological approach and addressing the impact of other strategies, such as low-floor buses and bus stop consolidation, as well as research on perception and satisfaction changes over time are recommended in order to maximize the benefits of implementing various improvement strategies on passenger perception.

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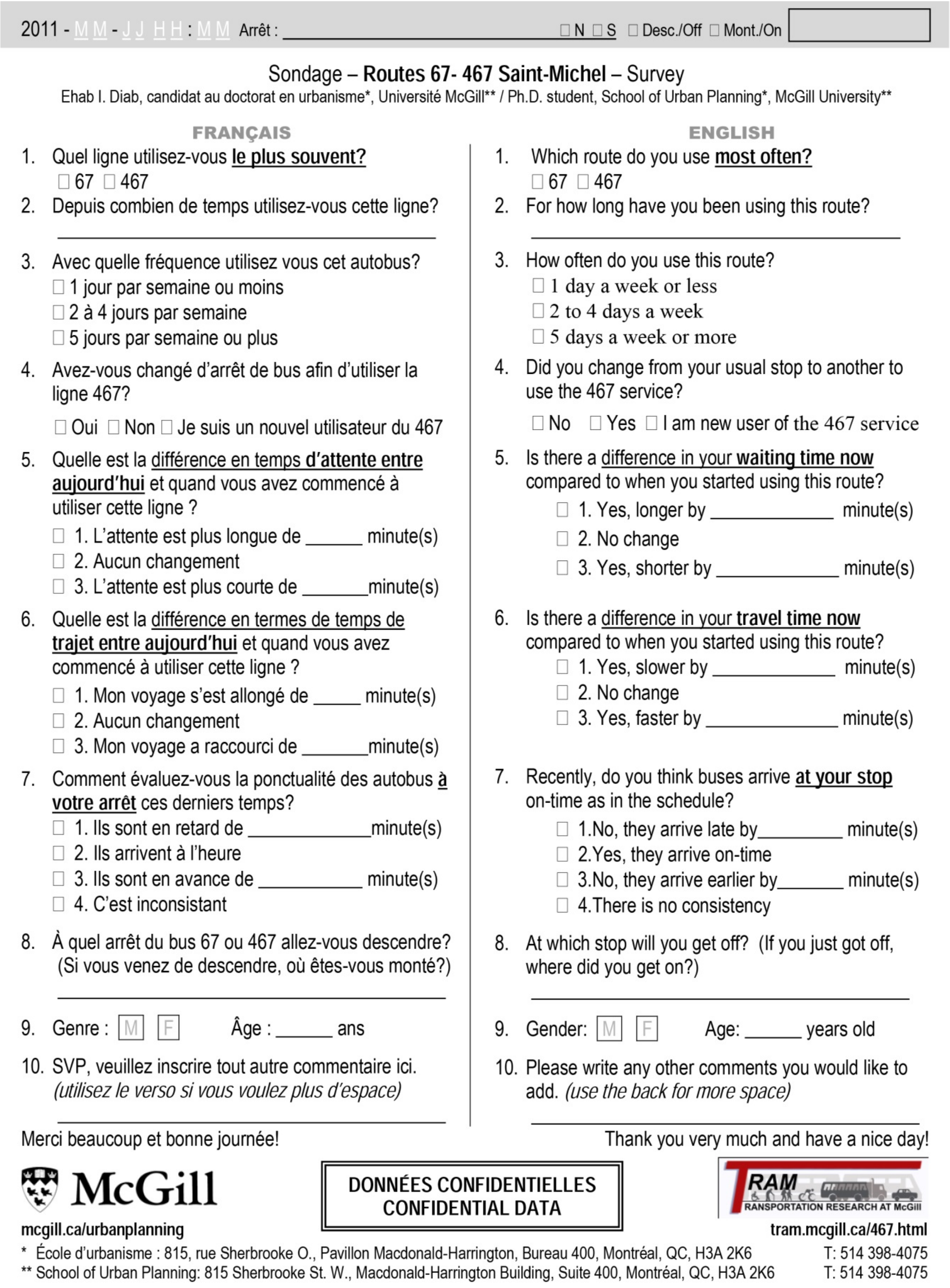
8 APPENDIX

8.1 APPENDIX ONE: 2011 SURVEY



2011 - M M - J J H H : M M Arrêt : ______________________________ ☐ N ☐ S ☐ Desc./Off ☐ Mont./On

Sondage – **Routes 67- 467 Saint-Michel** – Survey

Ehab I. Diab, candidat au doctorat en urbanisme*, Université McGill** / Ph.D. student, School of Urban Planning*, McGill University**

FRANÇAIS

1. Quel ligne utilisez-vous **le plus souvent?**
   ☐ 67 ☐ 467
2. Depuis combien de temps utilisez-vous cette ligne?
   ____
3. Avec quelle fréquence utilisez vous cet autobus?
   ☐ 1 jour par semaine ou moins
   ☐ 2 à 4 jours par semaine
   ☐ 5 jours par semaine ou plus
4. Avez-vous changé d'arrêt de bus afin d'utiliser la ligne 467?
   ☐ Oui ☐ Non ☐ Je suis un nouvel utilisateur du 467
5. Quelle est la différence en temps **d'attente entre aujourd'hui** et quand vous avez commencé à utiliser cette ligne ?
   ☐ 1. L'attente est plus longue de ______ minute(s)
   ☐ 2. Aucun changement
   ☐ 3. L'attente est plus courte de _______minute(s)
6. Quelle est la différence en termes de temps de **trajet entre aujourd'hui** et quand vous avez commencé à utiliser cette ligne ?
   ☐ 1. Mon voyage s'est allongé de _____ minute(s)
   ☐ 2. Aucun changement
   ☐ 3. Mon voyage a raccourci de _______minute(s)
7. Comment évaluez-vous la ponctualité des autobus **à votre arrêt** ces derniers temps?
   ☐ 1. Ils sont en retard de _____________minute(s)
   ☐ 2. Ils arrivent à l'heure
   ☐ 3. Ils sont en avance de ___________ minute(s)
   ☐ 4. C'est inconsistant
8. À quel arrêt du bus 67 ou 467 allez-vous descendre? (Si vous venez de descendre, où êtes-vous monté?)
   ____
9. Genre : M F Âge : ______ ans
10. SVP, veuillez inscrire tout autre commentaire ici. *(utilisez le verso si vous voulez plus d'espace)*
    ____

Merci beaucoup et bonne journée!

ENGLISH

1. Which route do you use **most often?**
   ☐ 67 ☐ 467
2. For how long have you been using this route?
   ____
3. How often do you use this route?
   ☐ 1 day a week or less
   ☐ 2 to 4 days a week
   ☐ 5 days a week or more
4. Did you change from your usual stop to another to use the 467 service?
   ☐ No ☐ Yes ☐ I am new user of the 467 service
5. Is there a difference in your **waiting time now** compared to when you started using this route?
   ☐ 1. Yes, longer by _____________ minute(s)
   ☐ 2. No change
   ☐ 3. Yes, shorter by _____________ minute(s)
6. Is there a difference in your **travel time now** compared to when you started using this route?
   ☐ 1. Yes, slower by _____________ minute(s)
   ☐ 2. No change
   ☐ 3. Yes, faster by _______________ minute(s)
7. Recently, do you think buses arrive **at your stop** on-time as in the schedule?
   ☐ 1.No, they arrive late by_________ minute(s)
   ☐ 2.Yes, they arrive on-time
   ☐ 3.No, they arrive earlier by_______ minute(s)
   ☐ 4.There is no consistency
8. At which stop will you get off? (If you just got off, where did you get on?)
   ____
9. Gender: M F Age: ______ years old
10. Please write any other comments you would like to add. *(use the back for more space)*
    ____

Thank you very much and have a nice day!

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DONNÉES CONFIDENTIELLES
CONFIDENTIAL DATA

TRAM TRANSPORTATION RESEARCH AT McGill
tram.mcgill.ca/467.html

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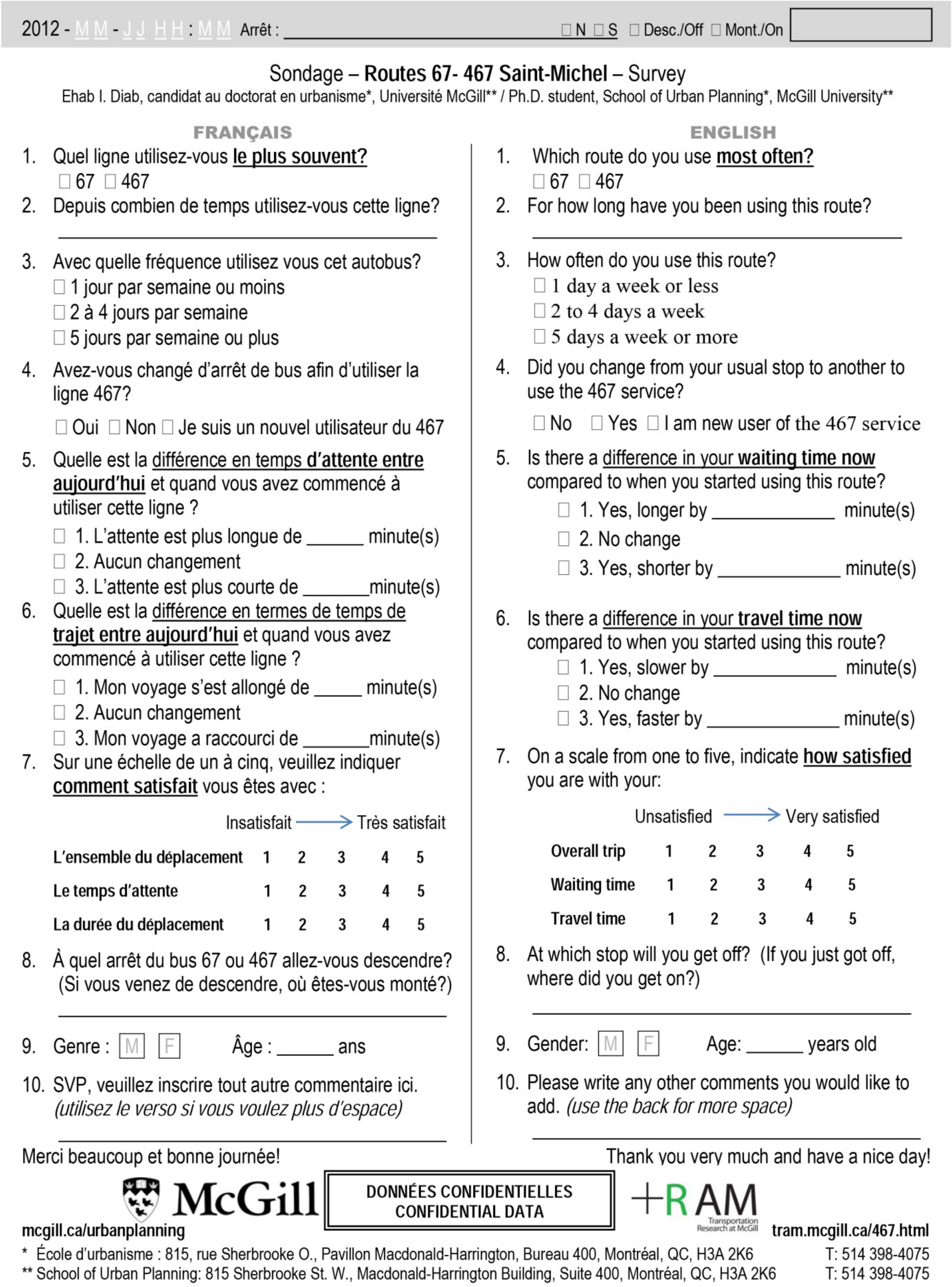
** School of Urban Planning: 815 Sherbrooke St. W., Macdonald-Harrington Building, Suite 400, Montréal, QC, H3A 2K6 T: 514 398-4075

8.2 APPENDIX TWO: 2012 AND 2013 SURVEYS



2012 - M M - J J H H : M M Arrêt : ______________________________ ☐ N ☐ S ☐ Desc./Off ☐ Mont./On

Sondage – **Routes 67- 467 Saint-Michel** – Survey

Ehab I. Diab, candidat au doctorat en urbanisme*, Université McGill** / Ph.D. student, School of Urban Planning*, McGill University**

FRANÇAIS

1. Quel ligne utilisez-vous **le plus souvent?**
   ☐ 67 ☐ 467
2. Depuis combien de temps utilisez-vous cette ligne?
   ____
3. Avec quelle fréquence utilisez vous cet autobus?
   ☐ 1 jour par semaine ou moins
   ☐ 2 à 4 jours par semaine
   ☐ 5 jours par semaine ou plus
4. Avez-vous changé d'arrêt de bus afin d'utiliser la ligne 467?
   ☐ Oui ☐ Non ☐ Je suis un nouvel utilisateur du 467
5. Quelle est la différence en temps **d'attente entre aujourd'hui** et quand vous avez commencé à utiliser cette ligne ?
   ☐ 1. L'attente est plus longue de ______ minute(s)
   ☐ 2. Aucun changement
   ☐ 3. L'attente est plus courte de _______minute(s)
6. Quelle est la différence en termes de temps de **trajet entre aujourd'hui** et quand vous avez commencé à utiliser cette ligne ?
   ☐ 1. Mon voyage s'est allongé de _____ minute(s)
   ☐ 2. Aucun changement
   ☐ 3. Mon voyage a raccourci de _______minute(s)
7. Sur une échelle de un à cinq, veuillez indiquer **comment satisfait** vous êtes avec :

	Insatisfait →				Très satisfait
L'ensemble du déplacement	1	2	3	4	5
Le temps d'attente	1	2	3	4	5
La durée du déplacement	1	2	3	4	5

8. À quel arrêt du bus 67 ou 467 allez-vous descendre? (Si vous venez de descendre, où êtes-vous monté?)
   ____
9. Genre : ☐M ☐F Âge : ______ ans
10. SVP, veuillez inscrire tout autre commentaire ici. *(utilisez le verso si vous voulez plus d'espace)*
   ____

Merci beaucoup et bonne journée!

ENGLISH

1. Which route do you use **most often?**
   ☐ 67 ☐ 467
2. For how long have you been using this route?
   ____
3. How often do you use this route?
   ☐ 1 day a week or less
   ☐ 2 to 4 days a week
   ☐ 5 days a week or more
4. Did you change from your usual stop to another to use the 467 service?
   ☐ No ☐ Yes ☐ I am new user of the 467 service
5. Is there a difference in your **waiting time now** compared to when you started using this route?
   ☐ 1. Yes, longer by _____________ minute(s)
   ☐ 2. No change
   ☐ 3. Yes, shorter by _____________ minute(s)
6. Is there a difference in your **travel time now** compared to when you started using this route?
   ☐ 1. Yes, slower by _____________ minute(s)
   ☐ 2. No change
   ☐ 3. Yes, faster by _____________ minute(s)
7. On a scale from one to five, indicate **how satisfied** you are with your:

	Unsatisfied →				Very satisfied
Overall trip	1	2	3	4	5
Waiting time	1	2	3	4	5
Travel time	1	2	3	4	5

8. At which stop will you get off? (If you just got off, where did you get on?)
   ____
9. Gender: ☐M ☐F Age: ______ years old
10. Please write any other comments you would like to add. *(use the back for more space)*
   ____

Thank you very much and have a nice day!

McGill

DONNÉES CONFIDENTIELLES
CONFIDENTIAL DATA

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mcgill.ca/urbanplanning tram.mcgill.ca/467.html

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