

ABSTRACT

Urban public transport has been developed during the last years, trying to achieve its growth to provide better social, economic and environmental benefits. The reliability of public transport is a key determinant when considering the quality of the service. From a passengers' perspective, service reliability it's a key factor to attract and retain passengers in the long term.

Since public transport is able to improve and ensure accessibility and livability of cities and since public transport might create a reduction of the negative impacts of increased car mobility, an increase in quality of public transport is necessary.

Reliability has been defined from different aspects of bus services in many studies. Buffer time indicators have been the preferred ones to analyze reliability since they reflect passenger-focused attributes. However, passenger's perception is lost from the time when it takes into account the total travel time.

Using AVL system data (automatic vehicle location) and GoCard (automated fare collection) data, which provides the progress of each vehicle as well as passenger loadings, has enabled the analysis of service reliability from the passenger's perception. All these data was analyzed to make an accurate assessment of the service reliability, comparing different measures. The selected measure was used to investigate the reliability performance for some of the Brisbane bus operations.





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1 GLOSSARY

-GPS: Global Positioning System is a space-based satellite navigation system that provides location and time information in all weather conditions.

-SmartCard: is any pocket-sized card with embedded integrated circuits. SmartCards can provide identification, authentication, data storage and application processing.

-Translink: Company responsible for leading and shaping Queensland's overall passenger transport system.

-AVL: Automatic vehicle location.

-PRDM: percentage regularity deviation mean.

-TT: travel time.

-RBT: Reliability Buffer Time.

-H: Headway.

-E: Mean.

-W: Waiting time.

-Hschedule: Headway schedule.

-Wnominal: Nominal waiting time.

-CDF: Cumulative density function.

-CoV: Coefficient of variance.

-BT: Traditional buffer time indicator.

-Sd: Standard deviation.

-BTi: Buffer time index.

-Skew: Skew-Width.

-New_BT: New buffer time indicator.

-EM: Early Morning.



-AM: AM Peak.

-MD: Mid-Day.

-PM: PM Peak.

-LE: Late Evening.

-GoCard: Name of the Smart card used in Brisbane City.

-CityCycle: A bike share scheme is a service in which bicycles are made available for shared use to individuals on a very short term basis. Bike share schemes allow people to borrow a bike from point "A" and return it at point "B".

-CityGlider: CityGlider is a high-frequency bus route operated by Brisbane Transport.

-CBD: Central business district, the commercial center of a city.



2 PREFACE

2.1 Origin of the project

This research was in a list of projects that were wanted to be done in The University of Queensland. More specifically, from the transport department of the School of Civil Engineering, it arise the willingness of studying the public transit reliability as it allows determine the quality of the service and the satisfaction of the passengers.

Professor Luis Ferreira, who has developed and delivered a large number of professional studies and courses in transport over the last ten years, has supervised the project.

Due to the large number of options that can be studied inside the public transport reliability framework, it was necessary to focus the current project on one of the most important indicators on passenger's reliability perception, studying waiting time distribution.

2.2 Motivation

Due to the mere background knowledge of public transport reliability, it has been taken this project as a challenge.

On the one hand, a study about the indicators proposed in past literature has been undertaken. This has provided an immersion on the transport reliability framework to understand the best ways to approach the project and analyze the service reliability with the obtained data.

On the other hand, using skills and abilities learnt during the studies in the past years, it was not enough to manipulate the data. The fact of having to learn new software and how to write the code for MATLAB to obtain the data in the correct format was also challenging.

Moreover, another of the motivations to decide about the project was thinking about the opportunity that this study will be for cities, to improve their public transport systems. The positive progress of new technologies gives the chance of developing new analysis indicators to improve in the public transport service. It gives desire to develop a good and accurate work, since it is the first time it can be calculated transit reliability with this type of information.





3 INTRODUCTION

3.1 Objectives

The concern with the impacts of reliability on operation efficiency for operators, as well as service effectiveness for passengers, brings about the need to identify and develop meaningful and consistent indicators of reliability in bus transit. Despite significant studies on indicators development, different indicators are recommended according to different application environments. Generally, the existing measures can be categorized into operator-oriented and passenger-oriented. This study focuses on passenger-oriented measures, which are believed to be more reasonable to quantify service reliability. The ultimate objective of this research is to develop a measure that can quantify passenger experienced reliability using operational data. Detailed research tasks include:

- Assessing current reliability measures relationship in identifying service reliability and identifying the most appropriate measure.
- Analyzing travel time reliability for public transport using data from GPS and Smart card systems collected for 6 months in Brisbane, Australia.

3.2 Structure of the project

The structure and content of this project is divided according to the following sections:

-Introduction of the origins and motivation of the project, followed by the explanation of its objectives and scope.

-A literature review of different studies that have been done, where definitions and measures are provided, to get familiarized with the entire topics, is presented in the following parts.

-After understanding the reliability service concepts, is presented the methodology, where the new developed measure is explained and the method that has been followed to realize the study is described. It is also included a briefly explanation of the two sources where the data has been obtained from and its characteristics.



- Explanation of how the data has been modified to be manipulated. It is also shown the results of comparing different methods and the different scenarios studied, with the methodology applied. Moreover, is presented a summary of the results obtained in the study analysis.

-A study of the economic viability and environmental considerations is done. The importance of the impact that the project can have in the environment and the cost of developing it, are explained.

Finally, are considered the overall conclusions and put forward a number of suggestions for future research.

3.3 Scope of the project

A new measure was developed to determine whether or not is worth it to use simple traditional ones or new complex formulas. The answer of this question was taken after comparing the new measure with the others used over the years. After determining which the best measure was, it was used to evaluate and determine Brisbane's public transport reliability using operational data. To complete the study, large amount of data was required. Translink provided the data to The University of Queensland. It included five months of data compilation in which, two routes bus location and passenger operations were registered, more than 30500 trips with passenger's information.

It is difficult to determine which method is better than the other in terms of analyzing the service reliability.

With this new developed measure, cities all over the world will be able to analyze public transport reliability from passenger's perception and use it as model to improve the service. It gives the desire to develop a good and accurate work, since it is the first time it can be calculated transit reliability with this type of information.



4 TRANSPORT RELIABILITY

Personal mobility has been increasing substantially during the last years. However, the public transport share has not increased in the same way. Many studies have been done to improve the service reliability performance in public transportation, as it is one of the main factors determining the quality of the public service.

Reliability concept is of great significance for transit passengers, operators and regulatory bodies. Liu, Lin et al. (2007). Reliability has been defined from different aspects of bus service depending on the groups of stakeholder's interpretation. Using a single measure to adequately cover all aspects seems to be counter-productive. Thus, it is reasonable to make a selection of those indicators, which will satisfy the different circumstances needs to determine reliability.

4.1 Transport reliability definitions

Service reliability is the matching degree of the promised and actual public transport services and its impacts on passengers. van Oort (2011).

There can be distinguished two types of definitions depending on whether they are general or specific.

General definitions describe reliability as the ability to provide a consistent service following the schedule patterns over a period of time. Specific reliability definitions refer to single or multiple aspects of service performance.

The magnitude of variability experienced by the passengers contributes to their perception of the service reliability. The result of service reliability is due to the interaction of the supply and demand side, which affects the waiting time and in-vehicle time of passengers. van Oort (2011).

Supply side perspective provides vehicle trips in time and space. Departure and headway variability are generated by late terminal departures and vehicle trip time deviations produce the mismatching of the schedule arrivals. At the demand side, the arrival time of passengers is very important to be considered, as they may arrive at randomly or planning their arrival with the vehicle departure forecast.



In literature review, different definitions of service reliability can be found depending on the reliability types;

Table 1 summarizes different types of reliability and their definition. The last four types only express parts of the aspects of service reliability.

Reliability types	Definitions (references)	Demand-side	Supply-side
General	Invariability of service attributes that impact decisions of travelers and providers (Abkowitz, Slavin et al. 1978)	√	√
Connectivity	Probability that the network nodes are connected (Bell 2000)		√
Travel time	Probability that the travel times remain below acceptable levels (Noland and Polak 2002)	√	√
Capacity	Probability that the transportation system can accommodate a given demand level at an acceptable level of service (Chen, Yang et al. 2002)		√
Headway	Ability that the vehicle operation can maintain a regular headway regularity (Turnquist 1980)		√
Schedule	Ability that the vehicle operation can adhere to the scheduled time table (Meyer 2002)		√
Waiting time	Ability that the bus service can minimize passengers' waiting time at the stop (Furth and Muller 2006)	√	
Cost, safety & comfort	Ability that the bus service can fulfill passengers' economic and psychological needs (Chapman 1976)	√	

Table 1. Types of reliability and definitions. (Ma, Ferreira et al. (2013))

4.2 Supply-side and demand-side measures

To analyze service reliability in public transport it is necessary to take into consideration both sides of the service, namely: supply and demand related factors. The supply side consists of the service provided by the operator, being trips in time and space. The demand side is defined as the passenger perspective including their behavior and experiences. van Oort (2011). While passengers are concerned mainly with total travel time, waiting time, in-vehicle time and seat availability; operators place more interest on adherence to schedule at origin, destination and intermediate points, headways and seat availability.

4.2.1 Supply-side

Looking at supply-side, a single trip is the basis of the operation. For the fixed service, vehicle trips are scheduled in time and space resulting in on-route schedule adherence at



all stops for infrequent service and headway regularity for frequent service. Every vehicle trip is scheduled to work in a given way, and variations are not considered. In the schedule, every vehicle trip is planned in a deterministic way and no variation is accounted for, vehicles depart on time from the terminal and drive perfectly according to the schedule. Nonetheless, during operations, actual vehicle trips suffer conflicts and deviations occur. This variability can be caused by different circumstances such as weather conditions, traffic and human (passengers and drivers) behavior. Variability increases due to a chain of events, along the trip; they sum up as the events follow.

The variations of the supply side can be classified into two types, namely, terminal departure time variations (distribution of schedule deviations of the vehicle trip departure at the terminal) and vehicle trip (distribution of the trip times along the route) time variations. van Oort (2011). Two components can be distinguished, from vehicle time; driving time and dwell time. Driving time consists of actual driving time between stops and unplanned stopping times when no boarding and alighting is enabling, for instance at traffic lights. Dwell time is the time for boarding and alighting at a stop.

4.2.2 Demand-side

Supply side enables passengers to make their trips to the destinations they have planned. The following parts explain the total journey for passengers as shows Figure 1.

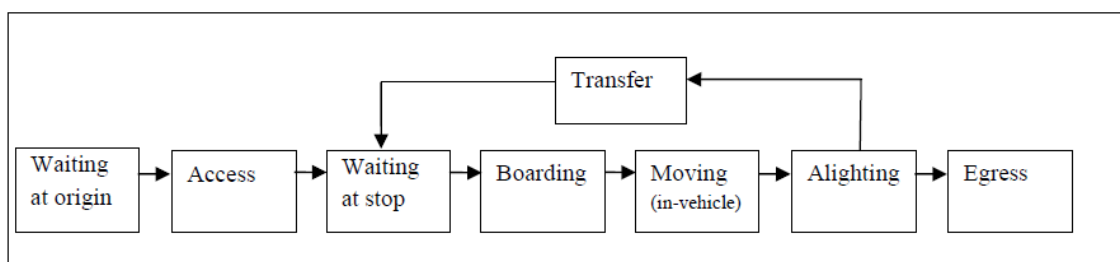


Figure 1. Passenger's total journey parts.(own source)

The journey starts with waiting at the origin if passengers plan the arrival at the stop, but not if they arrive randomly. Access time refers to the time needed to go from each particular origin to the stop where it is wanted to take the vehicle. When passengers reach the stop, they have to wait for a bus. During the trip, the elements to be considered are in-vehicle time, which is the time passengers spend in the bus, and transfers, which is meant to be the change of vehicle to reach the destination. Considering the whole trip, if passengers transfer to other vehicles, researchers take it as a new start of the trip, to



make it easier to analyze. After alighting from the bus, comes the time passengers need to go from the arrival stop to the destination, egress time. These time elements are randomly spaced and timed in reality.

4.2.3 Demand and supply interactions

Variations on the supply side produce service variability, while the matching of the actual and expected service perceived by the demand side defines service reliability. van Oort (2011).

Service reliability is influenced by the interactions between demand-side and supply-side. It can be seen the correlation in Figure 2.

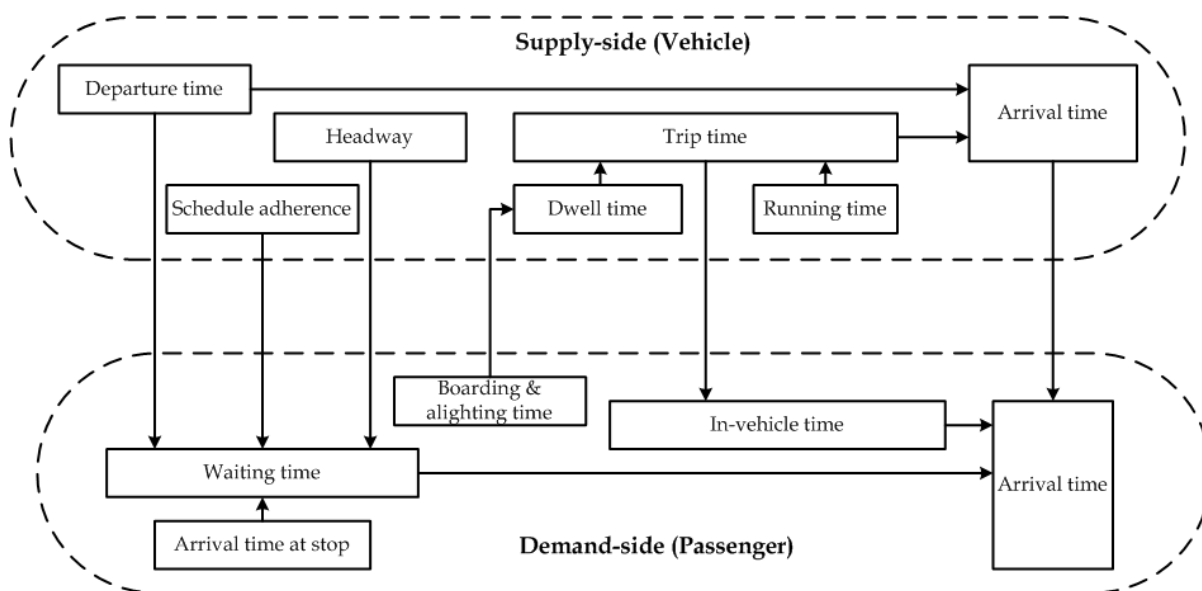


Figure 2. Interaction of components on demand-side and supply-side (adapted from (van Oort 2011)).

Figure 2 shows the differences and interactions of components on both sides, determining the total travel time. Each group of interest has different service attributes concern. Likewise, total travel time is the most concerned attribute of the service, considering the demand-side.

The increasing need to improve bus related reliability has brought about the need to select the most appropriate indicators. Indicators are defined as measures that people use in order to evaluate progress toward goals and objectives. Different types of indicators reflect different perspectives and assumptions. Litman (2007)



4.3 Review of reliability indicators

The purpose of reliability indicators should be to provide an easily understandable measure of how well buses operate to a timetable; so that travelers can determine for themselves how much time they should allow to make certain trips in addition to that indicated by the timetable. Currie, Douglas et al. (2012).

4.3.1 Current indicators

The most commonly used indicators have focused more on the service variability of the system rather than on the service reliability, concerning to passengers impacts. This section, evaluates the indicators that have been used, discusses attributes concerned and determines aspects that indicators should include to determine service reliability.

4.3.1.1 Statistical measures

Traditionally, there has been an emphasis amongst transport operators to collect statistics on operational performance, such as standard deviation or percentiles, as it is logic for the public transport nature. These measures remain popular because the statistics are easy to understand and the data is relatively easy to collect, especially if 'self-reported' by drivers. In addition, historical trends have usually been established and, as many operators use them, there is within industry comparability. Currie, Douglas et al. (2012).

Some researchers suggest using the standard deviation of real travel time on the whole route as the necessary and sufficient criteria for the route's reliability estimation Tseng, Rietveld et al. (2005). In addition to route travel time standard deviation the following measures for the travel time reliability estimation have been suggested: coefficient of variation of route travel time, difference between the 90th and 50th percentile of travel time, difference between the 80th and 50th percentile of travel time.

Statistic based indicators are objective and consistent and serve as the basic component of many other advanced headway regularity indicators, such as passenger focused indicators. However, purely statistical measures limit the study. They are generally familiar to statisticians but difficult to understand for passengers and to use for travel planning.



4.3.1.2 Punctuality

Punctuality can be defined as the extent to which the scheduled departure and arrival times are met, determining an average deviation from stops timetable. For routes with low frequency services, schedule adherence plays a very important role. To minimize the waiting time at stops with a tolerance probability of missing the trips, passengers are expected to coordinate their arrivals with the schedule vehicle departures. Punctuality indicator can also be used as the percentage of trips that depart up to m minutes late and n minutes early from the scheduled departure time M_a , Ferreira et al. (2013).

The major weakness of this kind of indicators is that they do not distinguish from whether the vehicle departs too early or too late, which is an important fact for passengers. Conversely, they can give reliability values to quantify the service performance and compare it with different scenarios. Although large samples of data are required, are cost effective, because the departing and arriving data can be obtained directly from vehicle monitoring systems. They are also great indicators to answer how and why the service is performing is good or bad.

4.3.1.3 Regularity

This indicator focuses the analysis of routes with high frequency services, since passengers arrive randomly at stops. When services are spaced evenly, the total waiting time of passengers is minimized.

Some indicators are defined based on headway distribution, such as standard deviation, coefficient of variance, average waiting time Osuna and Newell (1972) and probability-based headway regularity measure Lin and Ruan (2009). Others indicators are defined by comparing with scheduled headway, such as service regularity, headway ratio Strathman, Dueker et al. (1999) and percentage regularity deviation mean van Oort and van Nes (2004). Understanding regularity as the variation of headways, reliability indicators based on the percentage of performed trips within a defined bandwidth are very useful.

Being regularity indicators easy to obtain and understand, headway regularity measures are generally used to determine how headway irregularity is, whereas, headway ratio, like the percentage regularity deviation mean, indicates how 'much' headway irregularity is. Though, an important shortcoming for these indicators is they cannot provide the causes of the irregularity performance.



4.3.1.4 Irregularity

Irregularity has also been used to express headway deviations. PRDM (percentage regularity deviation mean) was introduced by Degman, Hakkesteeft et al. (1981) to show the deviation from the scheduled headway as a percentage of the scheduled.

These measures are based on scheduled data, like regularity and punctuality indicators. They cannot reflect the reliability perception of the demand side. There is no rule that determines the on-time tolerance interval. In addition, the difference between the two types of service frequency, namely high and low, is not well catered for. Nevertheless, irregularity indices perform well in indicating long vehicle gaps.

4.3.1.5 Travel Time

Travel time reliability can be defined as consistency in travel times, measured from day to day for the same trip, Carrasco (2012). Providing a reliable service can be related to keeping buses on schedule and minimising time variability as much as possible. The importance of travel time uncertainty has been the objective of many research studies. Kaparias, Bell et al. (2008). Studies have attempted to incorporate it into a model, for its importance. Most of them have concluded that, although travel time is an important factor affecting the traveler's route choice behavior, travel time variability can be even more important. However, the most important contribution to defining reliability measures has been made by Lomax, Schrank et al. (2003), who categorized them as; statistical range measures, buffer measures and tardy trip indicators:

Statistical Range Indicators: Calculated on standard deviation statistics, this measure naturally serves as an approximate evaluation of situations experienced by passengers. The coefficient of variation or percent variation of travel time provides a clearer picture of the tendencies and performance characteristics than the standard deviation by eliminating route length from the calculation. Moreover, percent variation is dimensionless enabling a comparison between links and routes. Lomax, Schrank et al. (2003) defined travel time gap as the average travel time plus or minus the standard deviation of travel time, and can provide the passenger with an idea of how much the travel time will vary.

Skew-Width Indicators: Skew of travel time distribution is the ratio of the difference between the 90th and 50th percentile and the difference between the 50th and 10th



percentile. Width of travel time distribution indicates the distribution compactness. Skew and width of travel time distribution measures are based on percentiles van Lint and van Zuylen (2005). Hence, the narrower the distribution is, the higher the reliability will be.

Tardy Trip Indicators: Define intolerable limit values in terms of additional time or percentage over the expected, determining extreme values of travel time. In most cases, these values are arbitrarily set. To estimate the limit of tolerable travel time range, it can be used a percentage of the average travel time in the peak. Otherwise, it can also be used travel time per unit distance instead of travel time, so as to provide a length-neutral way of grading the service performance Lomax, Schrank et al. (2003). Therefore, the results exceeding the expectations are termed a tardy trip Shaw and McLeod (1998).

The three travel time indicators are useful to provide reliability performance for passengers and operators. On the one hand, Statistical range indicator and tardy trip indicators eliminate route length influence, providing more detailed information than standard deviation. Hence, it is powerful to measure peak period reliability performance by comparing it with off-peak period performance in the form of a confidence time interval. On the other hand, It can be used Skew measure to determine the times of the day or days of the week period reliability van Lint and van Zuylen (2005). It depicts the leaning of travel time distribution to of side of the mean.

All measures presented, mainly focus on characteristics for the supply side. Punctuality and regularity are linked with the demand side as they make assumptions on the arrival pattern of travelers. They have a strong influence on waiting time, thus, as these measures do not make distinction between high or low demand stops, are more important for those stops with larger number of passengers boarding in the vehicles. These indicators do not quantify the impact the variability has on travelers.

The demand side indicators discussed below are better suited to determine service reliability from passenger's perception.

4.3.1.6 Transfer Time

Transfer time is defined as the time difference between the time of alighting from the previous transit line and the time of boarding the next vehicle Jang (2010). Transfer time can be calculated from scheduled stops. Thus, statistic indicators can be applied to measure transfer time reliability, such as the coefficient of variation of transfer delays



Turnquist and Bowman (1980). Goverde (1999) derived an expected transfer waiting time model, a function of arrival delays distribution, including the risk and implication of missing connections.

Transfer time measure is a powerful indicator that specifies passenger's service reliability. But, it is probably the lack of available information what makes it not that popular in literature. Nowadays, with the automatic fare collecting techniques, transfer time can be directly calculated from scheduled stops. Transfer waiting time indicators have great potential, since passengers tend to be more concerned with connectivity to the next service and waiting time at the next stop, they do not want to miss connections.

4.3.1.7 Additional travel time

Service variability may lead to an extension of passenger average travel time, since average waiting time per passenger may be extended due to irregular, early or late vehicles van Oort and van Nes (2004) introduced this indicator to express the effect of service variability on passengers more effectively than punctuality and regularity. The indicator is calculated from the average of all individual additional travel times. When calculating the additional travel time, two situations have to be distinguished, namely planned or random arrivals of passengers at the stop. If passengers arrive at random, exact departure times are not relevant anymore. In general, passengers do not use any schedule anymore.

Additional travel time is not commonly used in both theory and practice. But, using the average additional travel time per passenger as an unreliability impact indicator, the focus on quantifying service reliability, shifts from the supply side (variability) to the impacts on the demand side. It is a proper measure to indicate the impacts of service variability on passengers. Even so, it only addresses the expected extension of travel time and does not express the variability itself.

4.3.1.8 Buffer Time

Buffer time, is commonly defined as the difference between the 95th percentile and the average travel time Furth and Muller (2006). It indicates the extra travel time that passengers require arriving on time. The planning time indicates the total time that a passenger has to budget for the trip and it is defined as the percentile travel time.



Preferably, buffer time should be calculated considering the whole journey, but since the available data is restricted, the sum of two components is considered to estimate the total buffer travel time used by passengers to plan their trips. These two main components are waiting time and in-vehicle time.

Analytical and empirical studies have confirmed buffer time as a powerful tool in indicating and estimating service reliability Pu (2011). Empirical studies have supported buffer time as a better measure than traditional compactness indicators such as standard deviation Lam and Small (2001). However, buffer time calculation depends on the travel time distribution obtained from the demand side data. The poor use of buffer time based indicators is due to two main reasons, namely the existence of irreducible variability caused by the discrete nature of transit services; and the inability to address typical conditions and incident-influenced disruptions separately.

Buffer time indicators are perceived to be appropriate to reflect demand side's perception of reliability by using operational data. It is recommended since it indicates the total waiting time that a passenger should budget to guarantee catching the bus at expected stops along the route. Additionally, it enables to demonstrate the impact of travel time variability and it is directly related with the way passengers make decisions on planning their trips. It is an easy to understand passenger's focused indicator, which can be compared with different routes and periods of the day. Likewise, it can also give operators a view of unreliability evidence at different levels.

4.3.1.9 Waiting Time

From the perspective of passengers, the time they wait at stops, is the most important service component they focus on while deciding on using the public transport. It is one of the major causes preventing patronage increases. Traditional indicators of waiting time have a tendency to be based on mean values. Nonetheless, passenger's perceptions tend to be built on extreme values which are dependent on service reliability. When budgeting their arrival at stops, passengers are more concerned about extreme values. Extreme-value based waiting time is more sensitive to service reliability than mean-variance based average waiting time. Budget waiting time is defined for frequent services as the 95th percentile waiting time. It refers to as the total waiting time that a passenger should budget for a trip to avoid missing the bus. Impacts on operations and passenger planning are separated by the concept of extreme-value based indicators. Furth, Hemily et al.



(2006) show the calculation method of waiting time using automatic vehicle location data, thereby making the extreme-value based waiting time indicator more practical to obtain.

Since waiting time is from passengers perspective the most significant component of public transport service, should be included in all the reliability measures to analyze the service performance. However, it has not been generally used because of the lack amount of information. It is difficult to determine a measure which quantifies the amount of time passengers expend at stops waiting for the next bus to get in. Including waiting time attributes in service reliability measure would provide a great view of passengers experienced reliability, which mixed with supply side attributes of concern, would offer a complete approach of service analysis.

A framework to assess reliability indicators based on four criteria was developed by Currie, Douglas et al. (2012): (1) passenger focused; (2) easy to understand; (3) consistent and objective; (4) easy to compare and aggregate; and (5) insights into unreliability causes provided.

As follows, Table 2 related the service attributes with indicators and the respective sources used to analyze them.



Service attributes	Recommended Indicators	Reasons for selection					Data sources
		Passenger focused	Easy to understand	Consistent & objective	Easy to compare & aggregate	Provide insight into causes	
Punctuality	On-Time Distribution	Medium	Medium	Medium	High	High	Scheduled time and departure/arrival time
Regularity & Irregularity	Average Waiting Time	Medium	High	High	Medium	High	Scheduled headway and actual headway
Travel Time	TT Skew /Width	Low	Medium	High	High	High	Travel time and travel rate
	Median Travel Time	Medium	High	High	Low	Low	
	Misery Index	Low	Medium	High	High	High	
Transfer Time	Expected Transfer Waiting Time	High	High	High	Medium	High	Feeder service arrival delay distribution
Additional travel time	AddTravel Time	High	High	High	Medium	High	Journey travel time
Buffer Time	Planning Time	High	High	High	Low	Medium	Journey travel time
	Buffer Time Index	High	Medium	High	High	High	
Waiting Time	Potential Waiting Time	High	High	High	Medium	High	Waiting time distribution derived from headway

Table 2. Recommended sets of indicators and data sources. (Currie, Douglas et al. (2012)).

4.4 Attributes of concern

In a situation without service variability, public transport service would be reliable and would not be the concern of improving its reliability. Due to variability in actual vehicle trip times, and corresponding deviations of scheduled vehicle departure times and headways, waiting times at stops will increase on average per passenger, leading to longer travel times than the planned travel time. The total journey is defined by several components such as for



example; travel time of public transit modes tends to be split into waiting time, in-vehicle time, transfer time, and others.

Depending on the type of reliability analysis performed, either is from demand side or supply side, different components must be considered. From the point of view of demand side, attributes such as waiting time, in-vehicle time, seat availability or the actual total travel times are attributes of concern. While, from the demand side perspective, on adherence to schedule at origin, destination and intermediate points, headways and seat availability, are attributes that have been used to determine the quality of the service.

In Table 3 are displayed the reliability attributes of concern from both perspectives, giving a big picture of what elements are willing to include in the service reliability measures each group of interest.

Demand-side perspective	Supply-side perspective
Waiting time	Dispatching according to schedule adherence
Boarding time	On-route schedule adherence
Seat availability	Headway distribution
In-vehicle time	Individual-vehicle headway
Alighting time	Load-counts distribution
Total travel time	Individual-vehicle load count
Transfer time	On-time pull-out
Missed connections	Missed trips
Pre-trip information time	Breakdowns
Pre-trip time required for changes in access path	Late (crew) report (arrival)
	Driver proficiency
	Dispatcher and street-inspector proficiency

Table 3. Reliability attributes of concern to demand-side and supply-side (Ceder (2007)).

The indicators used to quantify the service quality are based on some of these attributes to perform the studies. The greater the number of attributes incorporated in the display, the greater complexity and difficulty the measure resolution will have.



Low variability of each attribute is directly related to high service performance. From the demand side and supply side perspective, considering both at the same time, the service would be perceived reliable by passengers and operators if the attributes fulfilling is high.

4.5 Evaluation criteria

The combined effects of headways, passengers' arrival pattern and vehicle departure time variation, determine the variation of passengers' waiting time at a stop.

Travelers are sensitive to how long it will take them to reach their destination, but are even more concerned with the reliability of their prediction of total travel time. A wrong travel time prediction results in either an early arrival at the destination or in a delay. None of these situations is appreciated by the traveler, with delays usually having more severe consequences for them, as could be arriving late to the workplace, therefore, not a tolerated situation.

Travel times play a very important role and it is important to know what factors can have influence in its variation. From these factors, there are three important ones that measures should include when evaluating public transport reliability;

- Distinguish impact of early and late arrival.
- Distinguish different stop demand.
- Distinguish different service attributes.

Although the supply-side indicators often help to illustrate the level of service provided to the passenger, they do not completely match the customer perception. Driving ahead or being late is completely different phenomena for passengers. The arrival pattern of passengers at the stop, where they depart, is of importance to determine the impacts the service has on them. If passengers arrive at random, the deviation from the schedule is not relevant anymore. Passenger waiting time is then minimized if actual headways are constant. Yet, if passengers use the schedule to plan their moment of arrival at their departure stop, the deviation from the timetable is of great importance. Early vehicles might lead to waiting the full headway. Late vehicles only extend the waiting time by the amount of delay, which is, especially in long headway service, most of times much less. Variability of the supply side thus affects the waiting time of passengers in an asymmetrical way.



It is very difficult to include this factor in a measure without having the information of the time passengers arrive to the stops. Thus, the new developed measure in this research has not made the distinction of early and late arrivals. The lack of information makes it impossible.

In terms of stop demand, it is important to know the characteristics of each route. Stops along the lines have different particularities. Stop demand is relevant since can modify the whole performance of the route reliability. It is drawn by passenger's distributions, which depending on the density of each stop, determines the importance for each stop.

Considering the relevant data that each stop hides related to passengers distribution, reliability measures should be able to define the stop demand and stop importance for each analyzed route. The new developed measure has been able to capture the stop demand, thereby has shown the stop importance for each route.

Including demand side and supply side attributes makes measures more complex. So far, one of the most important constraints, besides knowing the needs of each part of the service, has been having the mechanism to obtain the service information. As obtaining data systems have been improving, it has been possible to create more complex measures. However, they still have to improve up to being able to obtain the necessary information to implement measures with all the attributes of public transport reliability to define it with accuracy.

In vehicle and waiting time attributes have been taken into account to define the new measure. Hence, both sides of the service, demand and supply sides, have been considered to evaluate Brisbane's public transport reliability.

4.6 Summary

There has been significant research focus to improve the service reliability performance in public transportation, as it is one of the main factors determining the service quality.

General and specific service reliability definitions have been made by different researchers. All the definitions depend on the interaction of the supply and demand side of the service, as both parts are essential on determining its performance.

Considering both sides of the service, demand and supply, each of them has attributes of concern to quantify the service performance. As many attributes as possible should be taken



into account to define reliability indicators, to create a complete measure able to provide detailed information of each circumstance of the service. However, the more attributes included in the measure, the more complex it is.

During the public transport evolution, indicators have been defined to easily understand how well buses operate to a timetable. The indicators have focused in particular attributes of the service, such as; travel time, transfer time, punctuality. However, none of them have incorporated both sides of the service, trying to create a complex measure that defines the service performance completely.

Measures should include three important factors to define the service reliability performance;

- Distinguish impact of early and late arrival.
- Distinguish different stop demand.
- Distinguish different service attributes.

Driving ahead or being late affects passengers completely differently. The arrival pattern of passengers at the stop is of importance to determine the impacts the service has on those arrivals. Moreover, stop demand is relevant since it can modify the whole performance of route reliability.

The main constrain on developing a complete measure is the lack of data. A large database, with bus service performance and passenger's trip demand would be required.



5 METHODOLOGY

5.1 Evaluation of performance measures

The method followed to develop the current research is shown in Figure 3. After providing a literature review of past studies, where definitions and measures are provided, to get familiarized with the topics, the traditional measures were described. The study of the measures used previously, has helped to demonstrate the need for a new method to be developed. This new developed measure has to cover different attributes from both sides of the service, supply and demand sides.

Following the scheme, in this section, the new method is described in detail .The following sections deliver an analysis of the operational data provided, the comparison of the traditional measures with the new one, (where one will be chosen to analyze the Brisbane public service) and finally, the analysis of the service itself, to evaluate the case study performance.



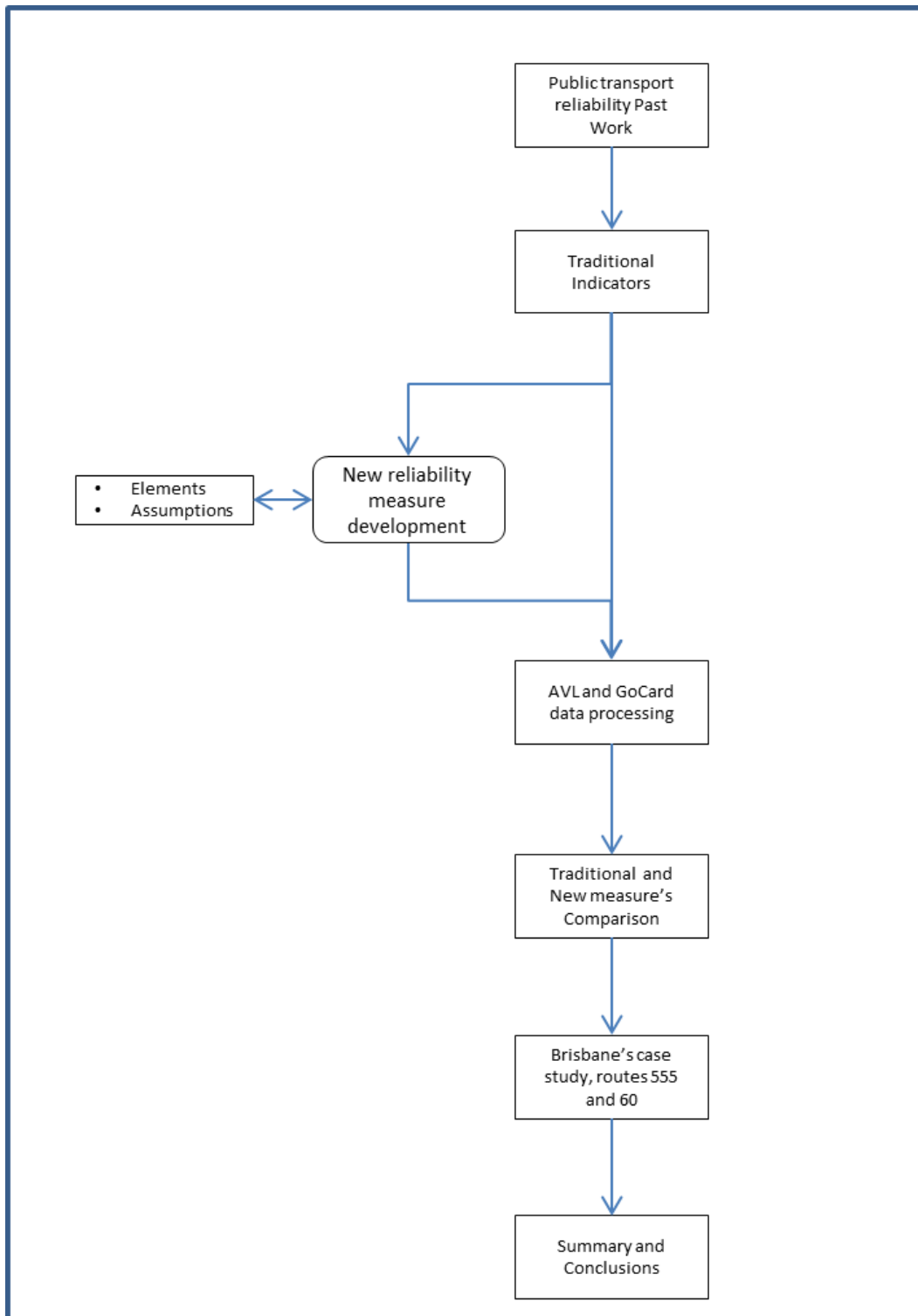


Figure 3. Research methodology flow chart.

When planning a trip, passengers tend to budget extra time for the variability in actual travel time for the purpose of catching expected bus at the departure stop, transferring successfully to the feeding service and arrive at the destination on time. As it has been stated, buffer



time has been defined as the difference between the 95th percentile and the average travel time. It indicates the extra budgeted time. The two main components that determine buffer time are waiting time and in-vehicle time, including passenger's perspective.

- *Reliability Buffer Time at stop j on line l due to variability in waiting time*

$$RBT_{l,i}^{waiting} = T_{l,i}^{waiting,95\%} - T_{l,i}^{waiting,50\%} \quad (5.1)$$

$$RBT_l^{waiting} = \sum_{i=1}^{n_l} (\alpha_{l,i} \times RBT_{l,i}^{waiting}) \text{ with } \sum_i \alpha_{l,i} = 1 \quad (5.2)$$

- *Reliability Buffer Time at stop j on line l due to variability in in-vehicle time*

$$RBT_{l,i-j}^{in-vehicle} = T_{l,i-j}^{in-vehicle,95\%} - T_{l,i-j}^{in-vehicle,50\%} \quad (5.3)$$

$$RBT_l^{in-vehicle} = \sum_{i=1}^{n_l-1} (\beta_{l,i-(i+1)} \times RBT_{l,i-(i+1)}^{in-vehicle}) \text{ with } \sum_i \beta_{l,i-(i+1)} = 1 \quad (5.4)$$

Where:

$T_{l,i}^{waiting,95\%}$, $T_{l,i}^{waiting,50\%}$ = 95th and 50th percentile value of waiting time at stop i on line l

$T_{l,i-j}^{in-vehicle,95\%}$, $T_{l,i-j}^{in-vehicle,50\%}$ = 95th and 50th percentile value of in-vehicle time from stop i to stop j on line l .

$\alpha_{l,i}$ = Proportion of passengers of line l boarding at stop i .

$\beta_{l,i-(i+1)}$ = Proportion of passengers of line l travel between stop i and stop $i+1$

Buffer time measure is the result of summing these two components;

$$RBT = RBT_l^{in-vehicle} + RBT_l^{waiting} \quad (5.5)$$



This indicator enables to demonstrate the impact of travel time variability. It is directly related with the way passengers make decisions on planning their trips and it is appropriate to capture demand sides perception using operational data.

The poor use of buffer time based indicators is due to two main reasons; namely the existence of irreducible variability caused by the discrete nature of transit services, and the inability to address typical conditions and incident-influenced disruptions separately.

Transit service quality measures have in the past separated waiting time from service reliability. Thus, is missed an important part of the unreliability experienced by passengers. Since waiting time is underestimated, service reliability is undervalued. The main component of travel time that is reduced by increased service reliability appears to be waiting time. Travelers attach a weight of 1.5 up to 2.3 to waiting times in urban transit systems Van der Waard (1988), which makes waiting time an important component of the total trip time.

Looking for a better analysis and approach to passenger's perspective, Muller and Furth (2009) introduced a waiting time distribution measure. It is based on headways distribution assuming the following statements;

- Passengers can arrive independently from vehicle arrivals.
- They can board the first arriving bus without considering the crowding possibility

From waiting elements during a passenger's journey, waiting at the platform is the most relevant. Headway is defined as the time between two consecutive arriving buses. Considering H as the bus headway for each stop, passengers arrive randomly generating a uniform waiting time distribution on the interval $[0, H_{\text{schedule}}]$. The basis of nominal waiting time used in planning applications is W_{nominal} , which is half the H_{schedule} , with H_{schedule} as the mean scheduled headway and assuming that headways have the same value of time. However, headways are not constant. Passengers arriving during long headways will have a higher average waiting time compared with those who arrive during short headways. Thus, mean waiting time is greater than $0.5E[H]$, which expresses half of the mean headway.



Thereby, mean waiting time has been calculated as;

$$E_{[W]} = 0.5 E_{[H]} \times (1 + cv_h^2) \quad (5.6)$$

Where W is waiting time and cv_h is headway covariance.

A relationship between service reliability and average waiting time has been known for many years. However, Furth and Muller (2006) asserts the average waiting time is not a measure that adequately reflects passengers' waiting cost. Therefore, equation (5.6) falls short of accounting for the impact of reliability on waiting time.

Furth and Muller (2006) derived formulas to estimate distribution of waiting time using headway distribution, as waiting time is determined by the headway regularity and schedule at the stop.

For short-headway service, passenger waiting time distribution can be estimated using the headway distribution as shown below:

$$f_W(w) = [1 - F_H(w)] / E_{[H]} \quad (5.7)$$

Where:

$f_W(w)$ = Probability density of passenger waiting time distributed over passengers.

$F_H(w)$ = Cumulative density functions of headway distribution.

$E_{[H]}$ = Expected value of headway.

Further defined $F_{waiting}(w)$ as the cumulative density function (CDF) of waiting time distribution, the reliability buffer waiting time for short-headway service can be written as:

$$RBT_{i,j}^{waiting,short-headway} = (F_{waiting}^{-1}(95) - F_{waiting}^{-1}(50))_{l,i} \quad (5.8)$$

Where:

$F_{waiting}^{-1}(95)$, $F_{waiting}^{-1}(50)$ = Inverse function of CDF of waiting time distribution, 95th percentile waiting time and 50th percentile waiting time.



Overcoming the difficulty of calculating the waiting time distribution without having the information from the demand side and after analyzing different measures and its functionality, it has been developed a new measure. It incorporates the scheduled passenger trip time, expected additional travel time per passenger and reliability buffer time as shown in Figure 4, to quantify the expected experienced passenger trip travel time from stop to stop.

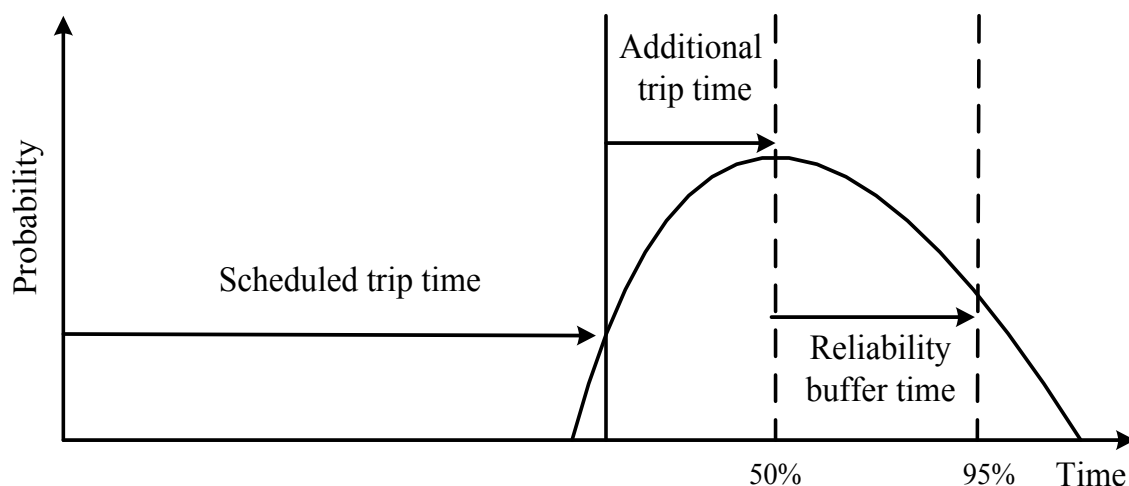


Figure 4. Components of expected experienced passenger trip travel time (van Oort (2011)).

5.1.1 Scheduled passenger trip time

The scheduled trip is basically the expected time that a trip is going to take from stop to stop. The information is usually provided by the public transport of the studied city, it is probably the easiest part of the measure to be calculated.

It is also straightforward to calculate additional and buffer in-vehicle time, since it can be get in-vehicle time and transfer time using smart card data. The distribution for in-vehicle time can be fitted using statistical distribution models. However, the difficult part is how to calculate additional waiting time and buffer waiting time.

5.1.2 Expected additional travel time per passenger

When calculating additional waiting time, two elements have to be considered, in-vehicle time and waiting time. Only in-vehicle time is calculated directly from smart card data. Two situations have to be distinguished to calculate the waiting time component, namely planned or random arrivals of passengers at the stop. The following is going to focus on random



arrivals as the research has been based on this kind of routes, characterized by having scheduled headways equal or lower than fifteen minutes. Main assumptions are;

- The examined period is homogeneous (including scheduled departure, trip time and headways).
- Passengers can catch the first bus that comes.

The expected waiting time per passenger is calculated using the coefficient of variation (CoV) and the actual headways ($H_{l,i}^{act}$) (Holroyd and Scraggs 1966, Osuna and Newell 1972).

$$E(T_{l,i}^{waiting}) = \frac{E(H_{l,i}^{act})}{2} \times (1 + CoV^2(H_{l,i}^{act})) \quad (5.9)$$

Where

$T_{l,i}^{waiting}$ = Passenger waiting time at stop i on line l .

If the service is regular, the expected waiting time will be equal to half the headway. Then the additional waiting time per passenger can be calculated as:

$$E(T_{l,i}^{add,waiting}) = \frac{E(H_{l,i}^{act})}{2} \times (CoV^2(H_{l,i}^{act})) \quad (5.10)$$

Where:

$E(T_{l,i}^{add,waiting})$ = Expected additional waiting time per passenger at stop i on line l .

It can be calculated the expected addition waiting time per passenger on the complete line, multiplying the proportion of boarding passengers per stop ($\alpha_{l,i}$) by each expected additional waiting time per passenger per stop of a line and sum them up.

$$E(T_l^{add,waiting}) = \sum_i (\alpha_{l,i} \times E(T_{l,i}^{add,waiting})) \text{ with } \sum_i \alpha_{l,i} = 1 \quad (5.11)$$

The average additional time is an appropriate indicator for the impacts of service variability on passengers. However, it only addresses the expected extension of travel time. To express service variability itself, the RBT indicator has been included.



5.1.3 Reliability buffer time

There are also two components to consider, when calculating buffer time, namely in-vehicle and waiting buffer time, which have been described in this section. Based on the available AVL and smart card data, in-vehicle time can be easily and directly obtained. Thus the reliability buffer time for in-vehicle time can be calculated. However, the waiting time data is not directly available and the manually collecting method seems to be less promising. Considering Furth and Muller (2006) approach on defining the probability of waiting an amount of time, as the proportion to the fraction of headways that are greater than w , it has been possible to calculate the waiting time distribution. As passengers' waiting time is determined by the headway regularity and schedule at the stop, there have been used Muller's derived formulas to estimate distribution of waiting time from the headway data base

After analyzing the different indicators, that have been used and including some of the most important aspects and factors that determine public transport reliability from passenger's perception, a new measure has been developed. Summing the three described components up and incorporating the formulas that have been detailing throughout this section, the final calculation of the new measure is as follows;

$$E(T_{l,i-j}^{\text{trip,exp}}) = T_l^{\text{trip,sched}} + \theta^{\text{add}} E(T^{\text{add}}) + \theta^{\text{RBT}} \text{RBT} \quad (5.12)$$

Where:

$T_l^{\text{trip,exp}}$ = Passenger experienced travel time on line l ;

$T_l^{\text{trip,sched}}$ = Scheduled travel time from on line l ;

$\theta^{\text{add}} = [\theta^{\text{add,waiting}}, \theta^{\text{add,in-vehicle}}]$: Value of additional time relative weights for waiting time and in-vehicle time;

$\theta^{\text{RBT}} = [\theta^{\text{RBT,waiting}}, \theta^{\text{RBT,in-vehicle}}]$: Value of reliability buffer time relative weights for waiting time and in-vehicle time;



$E(T^{add}) = [E(T_{l,i}^{add,waiting}), E(T_{l,i-j}^{add,in-vehicle})]$: A matrix of expected addition time for waiting time at stop i on line l and in-vehicle time from stop i to stop j on line l ;

$$E(T_{l,i}^{add,waiting}) = \frac{E(H_{l,i}^{act})}{2} \times (CoV^2(H_{l,i}^{act})) \quad (5.13)$$

$$E(T_{l,i}^{add,in-vehicle}) = \text{Median}(TT) - \text{Schedule}(TT) \quad (5.14)$$

$$E(T_l^{add,waiting}) = \sum_i (\alpha_{l,i} \times E(T_{l,i}^{add,waiting})) \text{ with } \sum_i \alpha_{l,i} = 1 \quad (5.15)$$

$$E(T_{l,i}^{add,in-vehicle}) = \sum_i (\beta_{l,i} \times E(T_{l,i}^{add,in-vehicle})) \text{ with } \sum_i \beta_{l,i} = 1 \quad (5.16)$$

$RBT = [RBT_{l,i}^{waiting}, RBT_{l,i-j}^{in-vehicle}]$: A matrix of reliability buffer time for waiting time at stop i on line l and in-vehicle time from stop i to stop j on line l ;

$$RBT_{l,i-j}^{in-vehicle} = T_{l,i-j}^{in-vehicle,95\%} - T_{l,i-j}^{in-vehicle,50\%} \quad (5.17)$$

$$RBT_l^{in-vehicle} = \sum_{i=1}^{n_l-1} (\beta_{l,i-(i+1)} \times RBT_{l,i-(i+1)}^{in-vehicle}) \text{ with } \sum_i \beta_{l,i-(i+1)} = 1 \quad (5.18)$$

$$RBT_{l,i}^{waiting} = T_{l,i}^{waiting,95\%} - T_{l,i}^{waiting,50\%} \quad (5.19)$$

$$RBT_l^{waiting} = \sum_{i=1}^{n_l} (\alpha_{l,i} \times RBT_{l,i}^{waiting}) \text{ with } \sum_i \alpha_{l,i} = 1 \quad (5.20)$$

This new measure is conceptually very appealing. It includes in-vehicle travel time and waiting time at stops. The calculation of the measure in this research was done with the additional and buffer time components, to analyze the travel waiting time. To determine if the developed measure can quantify passengers experienced reliability from operational data provided by public transport agencies, it was compared with a number of traditional used reliability measures.

The evaluating process that was followed, to determine which measure better expresses passengers experienced reliability, was to compare the analyzed measures one against



the other until all of them were compared. From the provided data, different scenarios were developed to test them one by one with the different measures. Once the scenarios were tested with all the measures, it was possible to compare the results and elect the best measure to proceed with Brisbane's case study.

The traditional tested measures were some of the ones defined in section 4.3.1. In Table 4 the measures calculation are described.

Name	Abbreviation	Equation	Comments
Coefficient Of Variation	CoV	$COV = \sigma/\bar{x}$	
Traditional Buffer Time	BT	$BT = (TT95 - TT50)/TT50$	Traditional Buffer time it is usually used as $TT95 - TT50$
Standard Deviation	Sd	$\sigma = \sqrt{\frac{\sum_i^n (x - \bar{x})^2}{(n - 1)}}$	
Buffer Time Index	BTi	$BTi = BT/\bar{x}$	$\bar{x} = \sum_i^n x_i/n$
Skew-Width	Skew	$Skew_{TTD} = (TT90 - TT50)/(TT50 - TT10)$	

Table 4. Traditional measures used to compare with the new developed measure.

To compare the measures, it was given a ranking for all the scenarios corresponding to each measure. The ranking was defined to elaborate a correlation between the measures and to determine their performance against each other.

After comparing the measures, one was selected for further testing.

5.2 Reliability analysis

Three different factors can be named to categorize the reliability influence analyzing operational data in this research:



- Days of the week
- Time of the day
- Route direction

For each category, diverse scenarios were defined to compare assorted setups and make more accurate the analysis.

To begin with, days of the week were classified into two different ways. First, the data was clustered distinguishing days of the week and weekend. Considering days of the week from Monday to Friday and weekend as Saturday and Sunday, this distinction was made as a result of two main reasons. On the one hand, the routes have different schedules depending if the service is due to be done during the week or not. On the other hand, because passenger behavior is diverse, the range of time and the destinations change depending on the day of the week. For this last reason, it was also necessary to do another analysis clustering the data by days, studying the service performance for every day of the week, from Monday to Sunday.

The results were analyzed to determine particular day tendencies and the differences and similitudes that days of the week and weekend have.

Moreover, each day of the week can be divided by 5 periods. It all depends on the time table that the routes have, as it is shown in Table 5.

Time Periods	Beginning	Ending
Early Morning (EM)	00:00:01	07:00:00
AM Peak (AM)	07:00:01	09:00:00
Mid-Day (MD)	09:00:01	13:30:00
PM Peak (PM)	13:30:01	18:00:00
Late Evening (LE)	18:00:01	23:59:59

Table 5. Different time periods of the day.

It is very important to understand that depending on the time of the day, the service is more overcrowded or not, increasing the variability of the service hence affecting the reliability. In peak time periods, the service is more crowded. Probably passengers have to wait for the next bus, as the one they wanted to get in was full. Additionally, the service can be slowed; the more people use the bus service at the same time, the more time it takes to board, alight. It has to be considered that peak time is considered to be the time



more people use public transport but also the period people use the roads. Thus, streets and highways can be more congested, reducing the service reliability. For all these reasons it is essential to make the periods of the day division.

Apart of the service attributes such as time periods and days of the week, inbound and outbound also have to be taken into account when analyzing the bus performance. Related to the other categories, the service performance is different depending on the direction of the bus, it is not the same to go from suburbs to the city than the other way round. For this reason, there have been categorized the scenarios by the direction, obtaining significant evidences of different service performances.

There have been created a total of 14 scenarios for each route, considering seven days of the week and the two bound, inbound and outbound. Each day of the week has been divided into five periods of time, depending on the peak hours.

5.3 Summary

This new measure developed here covers different attributes from, supply and demand sides.

To implement the measure, there were made two assumptions;

- Passengers can arrive independently from vehicle arrivals.
- Passengers can board the first arriving bus without considering the crowding possibility

This new measure is conceptually appealing. It includes in-vehicle travel time and waiting time at stops. The development of the measure was divided in three components. On the one hand, buffer time, which is directly related with the way passengers make decisions on planning their trips and it is appropriate to capture demand side perception.-On the other hand, scheduled passenger trip time, which the expected time that a trip is going to take from stop to stop. The last component, the expected additional travel time per passenger, determines the impacts of service variability on passengers.

The new measure was compared with other traditionally used measures. For that comparison, three different time categories were defined, namely:



- Day of the week
- Time of the day
- Route direction

The scenarios were used to compare different situations of the service, where its performance can vary depending on each of them.





6 CASE STUDY - BRISBANE

It would have been impossible to do this project without the information provided by TransLink, the urban public transport company in Brisbane. It can be distinguished two kinds of empirical data provided; automatic vehicle location (AVL) data and smart card (GoCard) data, both essential to progress with the investigation.

6.1 Automatic Vehicle Location

Automatic Vehicle Location Systems (AVL) combines a communication package, a computer display system and a positioning hardware to determine and transmit the geographic location of vehicles in real time. A picture of the vehicles' travel can be collected by a vehicle tracking system that uses GPS to determine the vehicle or vehicles' location during the entire route.

The Global Positioning System (GPS) is an advanced technology which has been proven to be very accurate. From every part of the planet at least four GPS satellites are visible at any time, transmitting its position information at regular intervals. Once received the information, of the at least three satellites required to pinpoint the location of the GPS unit, it can be determined the location by trilateration.

The recorded data can be used while the vehicle is operating or can be sent to a central location database to be stored and analyzed later.

AVL benefits can be classified as either user benefits that occurs to transit passengers or as operational benefits. Benefits of transit passengers are considered to be the ones that provide timesaving and reduce their risk. On the one hand, timesaving come from the reduction on waiting time at stops. Passengers' perception of the time they wait for the vehicle to come is higher than the actual time. AVL can help reduce the time needed to wait for the vehicle as can provide better on time performance and increase reliability. It gives more confidence, increasing passengers' satisfaction.

On the other hand, security is a factor that many users consider while using the public transport. AVL provides faster response in case of emergency as the vehicles' location is controlled at all time.



The operational side looks forward to providing a better service and reducing costs. Evaluating the benefits, it can be found; cost savings, additional revenues, schedule efficiency and image.

Staff members can be reassigned or reduced in number if their function can be done by the AVL, generating cost savings. As AVL provides an efficiency increase and reliable service, it will lead to additional revenues, attracting more users. By tracking vehicles as they move, a scheduled performance improvement can be obtained, allowing agencies to modify or relocate existing routes. It will also lead to increase the service image, as passengers will not feel they waste their time waiting more than they should do. Peng, Beimborn et al. (1999).

6.2 Fare payment Smart Cards

The payment public transport fares' system has had an evolution from its invention, until reaching the innovative Smart Cards method. It is nowadays being used in many public transit operators around the world, in place of traditional fare media such as magnetic stripe cards and paper tickets.

Automatic fare collection systems using smart card technology have become popular because they provide an efficient and cost-saving alternative to the manual fare collection method. Transit agencies are interested in this kind of technology, and many of them are now using the smart card to replace the traditional magnetic card, or tickets, as a viable payment option Blythe (2004). It is perceived as a secure method of user validation and fare payment Trépanier, Barj et al. (2004). It also makes the driver's job easier, as he or she no longer has to collect the fare. Furthermore, the smart card improves the quality of the data, gives transit a more modern look, and provides new opportunities for innovative and flexible fare structuring Dempsey (2008).

Smart cards are similar in look and size to credit cards. Each smart card can be identified by a unique serial number. It is a revolutionary invention from 1968, when, Dethloff and Grotrupp patented the developed concept of a plastic card. But, it was not until 1974 when Roland Moreno, patented the memory card concept, which enables it to save data. Nowadays, each card has a microchip, which is useful to store, process and write data; it can be used to determine how riders use transit and how they operate.



The cards can be registered to a given individual, or they can be anonymous. On these cards can be placed electronically a range of fare options such as travel cards or stored value (a monetary amount credited to the card which is debited as and when journeys are made). In terms of how the cards are used, on entry to a bus for example, card users are required to tap their card on a reader next to the driver Bagchi and White (2004).

Smart card data systems provide a new source of data that can be used to analyze travel behavior. These systems generate high quality data on journeys undertaken on public transport services and the customers undertaking those journeys. As it has been said, such data is linked to individual users. It helps the transport service providers to generate statistics to analyze the service, overcoming some of the deficiencies of the existing transport data. Transport service providers have to adopt strategies to obtain good results on analyzing data and to improve the quality of it. Smart card ticketing systems characteristics are detailed below:

- It is easy to use, the user does not have to insert a reader as is the case with magnetic and paper alternatives.. It is contactless and made of plastic, it is a permanent fare payment method that can be used during years, better than other systems that only last for one year or less.
- Smart cards have an easy payment tracking system. Accurate financial reports are easy to be processed for the transit authorities, thanks to the smart cards transaction easy manipulation.
- It is not 100% reliable but it reduces fraud compared to other systems. Users validate the right to travel when they get on the bus.
- It causes bus delay. The fact of being contactless makes boarding faster than other payment methods, but its not the fastest. The faster way would be to show a pass to the driver so he or she could recognize it and let passengers let in without making any queue and delay the bus progress.
- One of the major disadvantages of the system is its high cost. Costly equipment is requiered at the station and aboard the vehicle.
- Fare types and structures flexibility. Complex fare structures can be used, combining different zones, which is difficult with traditional payment systems. It can be easily modified by reprogramming the reading service.



6.2.1 GoCard (Brisbane)

Translink is the transport operator in the city of Brisbane, Australia. In July 2003, Translink started the smart card ticketing system project, to improve the efficiency and convenience of public transport. It cost \$A134 million to implement. It was not until three years later from the project proposal, in July 2006, when Translink tested the system with a thousand volunteers in the Redcliff Area. All the system was launched in February 2008 in Brisbane. The system is centered in the Brisbane area and suburbs, but, from its' launching date, the operational area has been expanded to the public network in South East Queensland, going from the north up to the Sunshine Coast, to the south until the Gold Coast.

Translink provide Go Card users with some advantages and incentives, to promote the use of the Go Card.

As shown in Figure 5. Different GoCard fare Figure 5, there are four fare types, which are cheaper than single paper tickets:



Figure 5. Different GoCard fare classes' samples.

- Adult is for use by passengers without concessions.
- Child is for use by children under the age of 15 years.
- Concession is for use by passengers entitled to a concession, such as full-time secondary and tertiary students, holders of a Pensioner Concession Card, and holders of a Repatriation Health Card, that benefits in a 50% reduction in all fares.



- Seniors is for use by passengers who have a Queensland Seniors Card issued by the Queensland Government.

Other incentives include a 20% discount applied during off-peak period trips -peak to encourage passengers to travel during non-busy hours. Peak is from 2am to 9am and 3.30pm to 7pm weekdays, except public holidays, while Off-peak is from 9am to 3.30pm and after 7pm weekdays until 2am the following day and all day weekends. To qualify for off-peak, the journey or segment must be commenced and completed before the off-peak period ends. Finally, if a Go Card user pays nine trips during the same week, the rest of the trips until the end of the week are free.

On buses, users must "touch on" and "touch off" for each service boarded. This means holding their card less than ten centimeters away of the reader in both cases. If users do not "touch off" will be charged a fixed amount which varies depending on the mode of travel. The system allows users to transfer between services without being regarded as starting a new journey, up to three times and within three and a half hours.

6.3 Data

From the data that was provided to The University of Queensland by TransLink, two routes can be differentiated. The database had the time and demand information for stop level of routes 555 and 60 both, inbound and outbound, stored during five months of bus service. The routes are described in this section. Also described here, is the analysis undertaken using the data, such as cleaning and organizing it to suit the structure needed to do the calculations and the process that was follow to calculate all the elements desired to evaluate the public transport service reliability of the studied routes.

6.3.1 Routes 555 and 60

The analyzed routes are 555 and 60. Two very different routes that let study diverse scenarios. The characteristics of each route are described below.

Inbound route 555 as shown in Figure 6, goes from Loganholme station to Elisabeth Street Stop 82 in the center of Brisbane city. The return services have one more stop than the inbound services. The entire journey takes about forty minutes and it is a very used service, as takes passengers from the city to the eventful Loganholme station going through



important places of interest and vice versa. On the way to the city, there are several stops of interest, which make the line busy in certain times of the day. There can be found; shopping malls, Ikea center, three different schools and one university, in addition to three interchange bus stops. The headway between a bus and the following is meant to be of fifteen minutes.

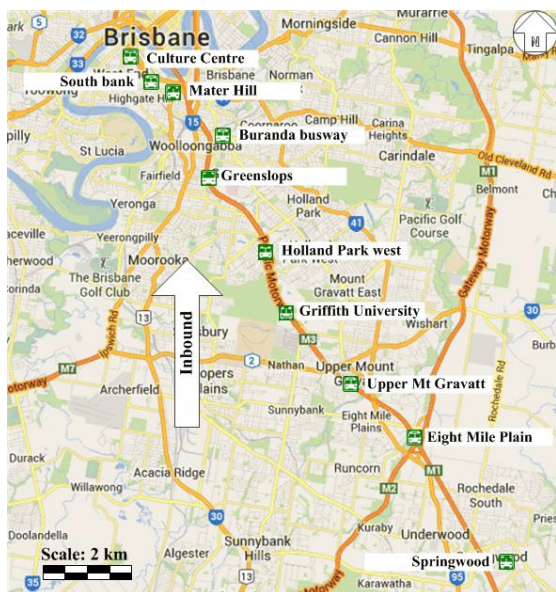


Figure 6. The inbound bus route 555-service operation maps.

Route 60 (CityGlider), provides high frequency services from West End to Teneriffe. The CityGlider service links to the CityCycle bike hire scheme, having bike hire stations near CityGlider stops. This enables access to the new bus service from Teneriffe, CBD, South Brisbane and West End.

The CityGlider is part of Brisbane City Council's commitment to reduce traffic congestion and improve public transport across the inner city. In addition, route 60 links to bus way and rail connections, CBD attractions and new residential developments.

CityGlider runs every five minutes during peak and every 10 to 15 minutes during off-peak. This is the first service in Brisbane to operate 24 hours on Friday and Saturday and 18 hours every other day. Due to its frequency of the service, a written timetable is not produced, however specific service and stop information can be found through the journey planner function



6.4 Summary

Two kinds of databases were used here to analyze Brisbane's public transport. On one hand, a picture of the vehicles' travel was collected by AVL systems. Using GPS determined the vehicle or vehicles' location during the entire route. This provided information about the duration of travel between each stop and the possible problems that each vehicle can have along the line. On the other hand, GoCard database provided the number of passengers that boarded and alighted the vehicles in each stop, giving a number of on-board passengers for each part of the trip.

The analyzed routes were 555 and 60, low and high frequency services respectively. Two very different routes that enabled the study of diverse services. All the defined scenarios were tested to analyze the service performance for each of the routes.





7 DATA ANALYSIS AND RESULTS

7.1 Processing the data

Initially the data was written in Excel to have a picture of the information had. The data was organized into chronological order, giving the trip's information for each stop of the line.

Before performing the necessary calculations to extract the results of the new measure, the definition of Headway was carefully analyzed to determine the possible errors that could be found in the database. On the one hand, it was considered that some data could be missing. To check if there was missing data, it was to be established that between two bus arrivals, the difference in schedule arrival time should be 5 minutes or 10 minutes depending on the route that was being studied, route 60 and 555 respectively. If it was true, the trip was written down. Otherwise, the two following trips were compared. Another consideration was taken before calculating the headway. It could occur that in a sequence of two buses, where number one was supposed to arrive before number two, it arrived after. In that way, considering this situation, it was not the same to calculate a headway sequence with these three buses as some values would be negatives. To obtain the correct information of two buses that arrived consecutively to a stop, the data was reorganized.

To study different scenarios it was needed to separate the data and categorize it. Four groups were generated to study them separately on each of the bounds, making a total of eight. After calculating the headways, there were calculated the rest of elements of the indicator to generate the results of the service performance. In the calculations used to derive the new measure, the median of the distributions was used instead of the average. Median travel time excluded the impact of the outliers with extremely long values, is recommended to measure the center.

The trips were grouped in periods of thirty minutes and each period related to the time ranges of the day, to make the analysis malleable. The results were extracted both for each day of the week, and for the days belonging to the week and weekend, grouped in two.



7.2 Comparison of reliability methods

7.2.1 Correlation among reliability measures

For each of the reliability indicators there were obtained the results of different scenarios. As the results did not provide the same units, it was not possible to compare them directly. To the values obtained for each of the measures in the different scenarios, there were given a ranking number from one to the number of samples (n) had in each case. To the lowest value of each measure it was conferred the number one, increasing one by one up to reach the highest value, which was given the number 'n'. This process was performed for each scenario, generating a particular ranking to each one. Thus, the ranking was used to make a table of correlation between the measures, obtaining a total of twenty-eight correlations. The following Table 6-Table 9, which are part of the performed study, show the significance of the correlations.

	<i>SD</i>	<i>CoV</i>	<i>BTi</i>	<i>Skew</i>	<i>BT</i>	<i>New_BT</i>
<i>SD</i>	1					
<i>CoV</i>	0.85	1				
<i>BTi</i>	0.86	0.92	1			
<i>Skew</i>	0.16	0.02	0.22	1		
<i>BT</i>	0.94	0.76	0.87	0.30	1	
<i>New_BT</i>	0.70	0.53	0.56	0.30	0.74	1

Table 6. Route 555 measures correlation, for inbound direction on Mondays.

	<i>SD</i>	<i>CoV</i>	<i>BTi</i>	<i>Skew</i>	<i>BT</i>	<i>New_BT</i>
<i>SD</i>	1					
<i>CoV</i>	0.85	1				
<i>BTi</i>	0.76	0.85	1			
<i>Skew</i>	0.12	0.16	0.44	1		
<i>BT</i>	0.89	0.78	0.91	0.36	1	
<i>New_BT</i>	0.67	0.45	0.41	0.08	0.58	1

Table 7. Route 555 measures correlation, for inbound direction on Sundays.



	<i>SD</i>	<i>CoV</i>	<i>BTi</i>	<i>Skew</i>	<i>BT</i>	<i>New_BT</i>
<i>SD</i>	1					
<i>CoV</i>	0.96	1				
<i>BTi</i>	0.64	0.74	1			
<i>Skew</i>	0.40	0.52	0.85	1		
<i>BT</i>	0.71	0.80	0.98	0.82	1	
<i>New_BT</i>	-0.03	-0.03	0.09	0.02	0.11	1

Table 8. Route 60 measures correlation, for inbound direction on Mondays.

	<i>SD</i>	<i>CoV</i>	<i>BTi</i>	<i>Skew</i>	<i>BT</i>	<i>New_BT</i>
<i>SD</i>	1					
<i>CoV</i>	0.95	1				
<i>BTi</i>	0.85	0.89	1			
<i>Skew</i>	0.37	0.41	0.65	1		
<i>BT</i>	0.86	0.85	0.97	0.67	1	
<i>New_BT</i>	0.34	0.39	0.38	0.06	0.31	1

Table 9. Route 60 measures correlation, for inbound direction on Sundays.

In Table 8Table 9, the maximum value is one and the lowest is minus one. From this range of values, a correlation higher than 0.70, can be considered consistent. Muller and Furth (2009). After analyzing the correlation tables, it was stated that the results obtained from them, could not draw consistent conclusion to determine the appropriate measure to follow with the Brisbane's study.

In most cases, traditional buffer time has strong correlation with Sd and CoV, very strong (almost value one) with Bti and highly variable correlation with Skew and the new measure. For other correlations, no assertion was consistent enough. Thus, more detailed analysis was needed to elect one measure. Nevertheless, before following with the study, it was specified that Standard Deviation, Buffer Time Index and Skew-Width measures could be excluded from being elected as the appropriate ones.

On the one hand, standard deviation is a not used measure nowadays, because it is significantly influenced by the distance of the route and does not reflect passenger's perspective reliability. For this reason, it showed better correlation between the standard deviation and the new measurement in route 555 than it did in route 60. It cannot be used to compare different length routes. Moreover, Skew indicator was the less correlated one. The



relation with the other measures and in particular with the new measure was very low. Besides, Skew and Bti, are both influenced by the outliers, fact that makes them less reliable. Even though, Bti and the traditional buffer time have approximately the same correlation with the other measures, traditional buffer time has higher correlation with the new method than BTI. It is due to both are divided by the median, approximating the results to reality more than Bti which is divided by the mean.

On the other hand, traditional buffer time, coefficient of variation and the new developed measure were not excluded. Conceptually, all these three measures are strong to reflect the service reliability performance. Based on past experience, coefficient of variation and traditional buffer time are the two that have most been used and have served as pattern to evaluate the service performance. The traditional and new buffer time indicators include passenger's attributes, which make them suitable to reflect the reliability from their perception. Finally, these measures give dimensionless results that make them easily comparable with each other and with different scenarios.

For these reasons, the study was done comparing the results of coefficient of variation, traditional buffer time and new buffer time, using normalized data. The data used in the correlations was normalized, obtaining numbers from zero to one, for each measure, to compare them directly. The comparison was made with the results obtained from 6 am to 11,30pm trips, dividing the abscissa axis in periods of thirty minutes and the ordinate axe from 0 to 1 divided in ranges of 0.05.

Analyzing the charts, there were highlighted some differences. For the route 555, the values obtained from the different measures do not show significant differences during the peak periods, all three follow the same pattern. As for off –peak periods, there is reflected a clear distinction with the new measure values and the results of the other two measures. Even the whole route is reliable as the traditionally used measures indicate, for the passengers, at some stops, the service does not have to be reliable, especially, when they have to plan more waiting time to catch the expected bus. For this reason, as the new measure considers additional buffer waiting time and waiting time, it is reasonable that it gives higher results, it also gives reasons of existing linking problems from stops that generate lower reliability.

Analyzing route 60, values provided by the new measure compared to the traditional ones, show dissimilarities. The pattern drawn by the measures are different. The coefficient of variation and traditional buffer time, have almost the same values in comparison with the new



measure. It has to take into account when analyzing the new measure that the numbers of passengers who use the buses are considered. Thus, if there is low reliability in some section of the line, such as last stops, that have in turn little demand, it indicates that unreliability does not affect passengers. Besides, if there is a period of the day with a lot of demand and unreliability results for the traditional measures are significant, the new measure indicates higher unreliability than the rest, as more people is influenced by the service performance.

Figure 7-Figure 10 show a sample of the results. The coefficient variations, traditional and new buffer time measures, are shown for each scenario.

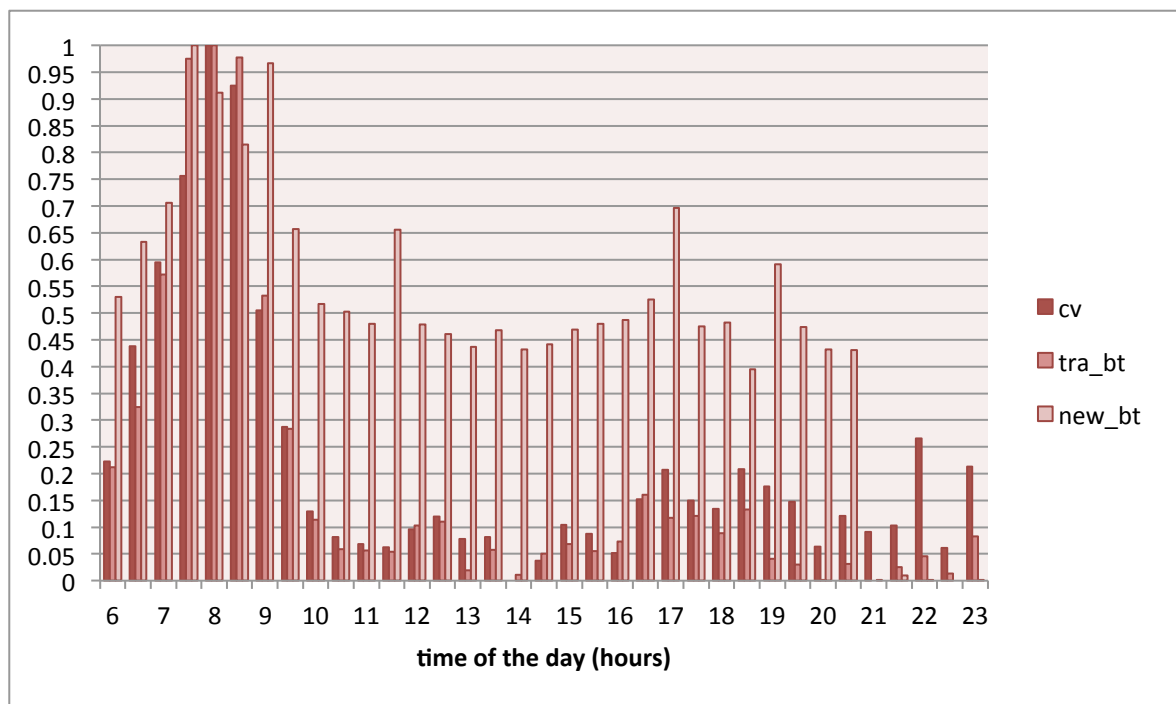


Figure 7. Indicators comparison for inbound 555 trips on Mondays.



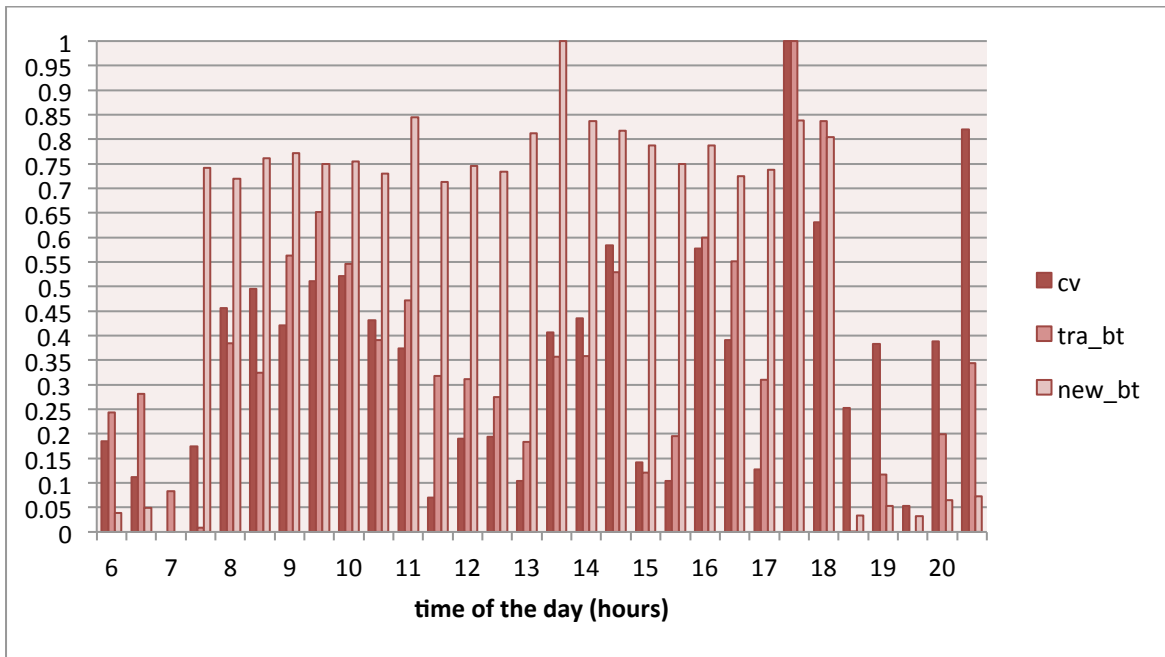


Figure 8. Indicators comparison for inbound 555 trips on Sundays.

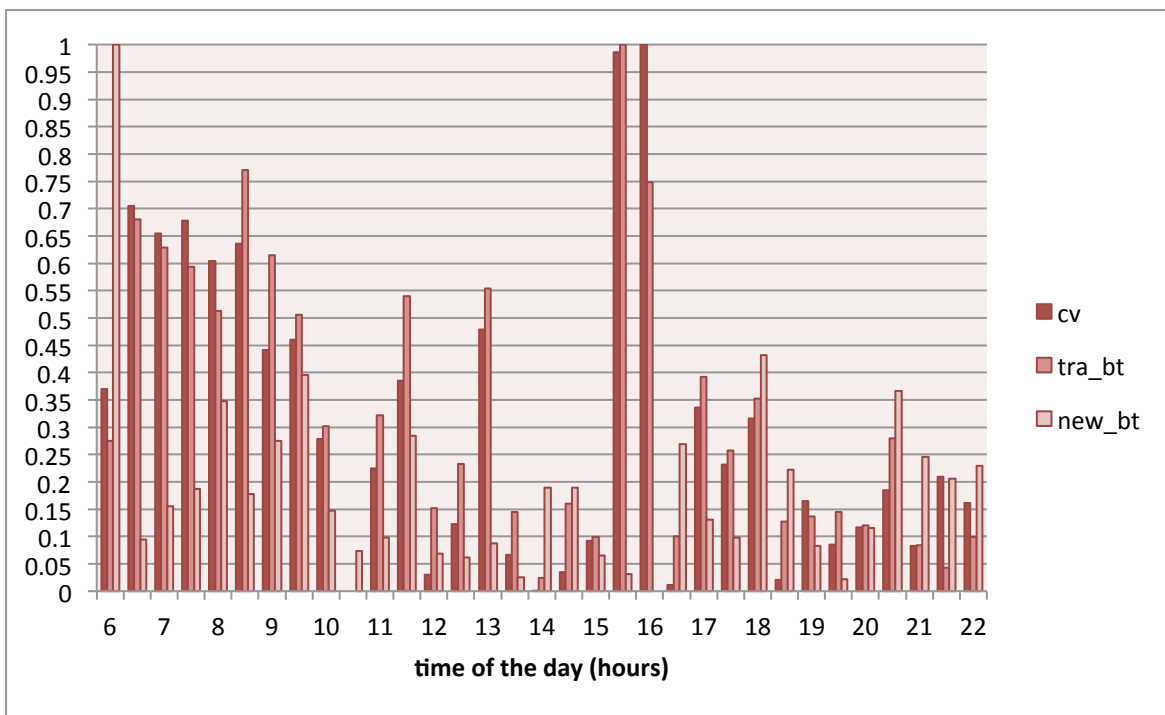


Figure 9. Indicators comparison for inbound 60 trips on Mondays.



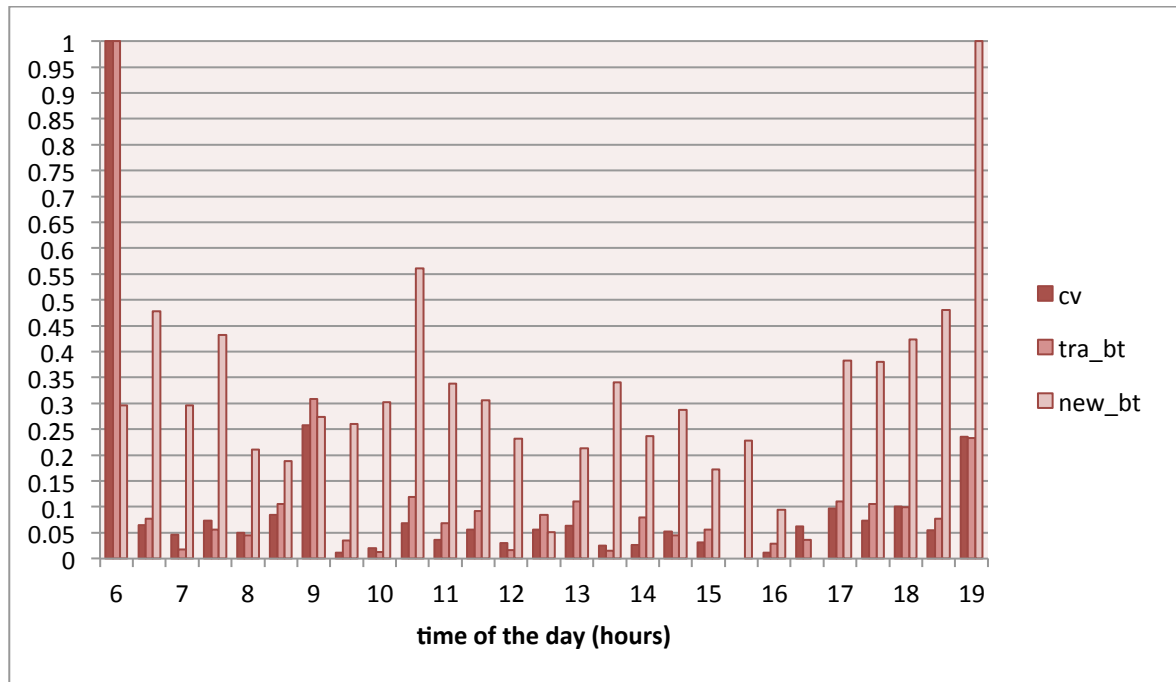


Figure 10. Indicators comparison for inbound 60 trips on Sundays.

After analyzing the complete performance of the measures in the different scenarios, a measure was selected to continue with Brisbane's case study.

The first analysis helped to exclude three measures that did not provide as useful information as the rest. There is not an established criterion to choose which the best measure is. But, after doing the second analysis, was concluded that, although the two traditional measures follow the same pattern and have been suitable over the years to study the service reliability, the new measure was going to be used to proceed with the study. The decision was not easy to be made, but the new measure has strong explanatory power and can be self-explained. Based on the experience it follows reasonable trends. It takes more factors into consideration than the rest. All the procedures followed on the calculations make sense. Moreover, it includes different factors that can reflect the service reliability. For instance, if one factor performance changes or has a variation, this measure can still capture the reliability influence. Based on its conceptual definition, which includes passenger's attributes, can show some performance differences that operators can't detect with other measures.

Distinguishing actual from perceived performance, coefficient of variation and traditional buffer time, are two indicators, which reflect the service performance more from the operational side than the demand side. Both are based on travel time data to calculate the service reliability, missing passenger's information by not including as many factors as the



new measure. Traditional buffer time indicator approaches on trying to determine passenger's perception, by calculating the extra travel time that passengers require arriving on time. Further, the new measure can reflect passenger's perception as it does not only include travel time factors calculations, but also includes waiting time distribution elements to calculate the service reliability.



7.3 Results for Different Scenarios

Table 10 to 13 summarize the service reliability performance under different scenarios. The data were disaggregated by route, direction, day of the week and time of day. For time of day, early morning and late evening were excluded from the analysis since the service performance is not a major concern for these time periods.

555	AM			MD			PM		
Inbound	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
MON	8.6	12.3	10.8	5.2	8.0	6.2	5.1	8.5	6.0
TUE	8.5	12.5	10.5	5.2	9.7	6.7	5.1	6.3	5.6
WED	8.7	10.3	9.7	5.5	7.8	6.5	5.1	8.4	6.1
THU	7.6	11.3	9.4	5.6	7.4	6.3	5.1	8.2	6.0
FRI	7.7	11.0	9.1	5.3	6.5	5.9	5.2	8.1	6.2
SAT	4.9	5.4	5.2	5.4	7.1	6.2	5.5	8.1	6.0
SUN	-0.3	5.4	2.9	5.0	6.0	5.4	5.1	7.3	5.7

Table 10. Waiting budgeted time, route 555 inbound (min).

555	AM			MD			PM		
Outbound	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
MON	5.7	13.0	9.7	5.8	10.7	6.9	5.4	11.5	7.7
TUE	8.0	12.5	10.1	6.1	9.6	7.0	5.9	11.6	7.9
WED	7.4	10.1	8.6	6.2	10.4	7.8	5.8	11.7	8.1
THU	7.5	12.8	9.2	6.0	9.2	7.1	6.3	10.9	8.3
FRI	6.5	9.4	8.0	6.0	8.9	6.8	5.8	10.8	8.4
SAT	5.0	5.8	5.4	5.3	7.0	6.0	5.2	6.3	5.6
SUN	-0.6	5.2	1.6	5.1	6.7	5.7	5.0	6.2	5.4

Table 11. Waiting budgeted time, route 555 outbound (min).

60	AM			MD			PM		
Inbound	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
MON	3.3	7.8	5.2	3.3	7.8	4.3	3.0	6.4	4.6
TUE	4.3	5.8	4.8	3.3	6.1	4.2	3.1	6.4	4.3
WED	3.5	5.0	4.2	3.2	7.4	4.6	3.3	7.3	4.5
THU	3.7	5.2	4.7	3.4	6.3	4.2	3.6	5.9	4.4
FRI	3.3	5.1	4.6	3.9	7.0	4.6	3.5	5.7	4.7
SAT	4.8	5.6	5.1	4.4	6.0	5.2	4.2	5.3	4.8
SUN	4.9	5.1	5.0	4.6	5.1	4.8	4.2	5.7	4.7

Table 12. Waiting budgeted time, route 60 inbound (min).



60	AM			MD			PM		
Outbound	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
MON	3.4	7.4	4.7	3.5	5.1	4.3	4.3	6.2	5.0
TUE	3.6	5.4	4.5	3.8	4.7	4.5	2.7	5.8	4.6
WED	2.5	5.4	3.7	3.7	4.9	4.3	4.1	8.1	5.5
THU	2.7	3.8	3.2	4.0	4.7	4.3	3.9	7.0	4.9
FRI	2.8	5.0	3.8	4.1	5.8	4.6	4.4	6.4	5.3
SAT	6.0	6.6	6.2	5.3	6.5	5.9	5.3	6.2	5.7
SUN	5.1	7.6	6.1	4.9	6.2	5.5	5.3	6.0	5.7

Table 13. Waiting budgeted time, route 60 outbound (min).

7.4 General

As anticipated, service performance on weekdays has different reliability than that on weekends. Monday was found to be less reliable than other days. The service reliability improves as the week advances until Friday. Reliability performance on Sundays is relatively better than that on Saturdays.

Another insight could be obtained by examining the reliability performance for different time periods of day. The three periods of the day considered have different performances, as people's behaviour varies during the day. The best service performance occurs between peak hours. Comparing both peaks, the performance is better for PM than for AM peak

The service direction plays an important role. There are different trend performances for the inbound and outbound services. Depending on the direction, the characteristics of the route can vary, hence, affecting the service performance along the whole line.

7.4.1 Comparing scenarios

The service reliability for route 555 trends to improve during the week, having worse performance on Mondays and better on Sundays. Moreover, the service reliability varies depending on the direction of the line.

For the days of the week, Mondays have the worst performance, with peaks over 12 and 8 minutes during AM and PM periods respectively, compared to peaks of 6.7 minutes for Sundays, which are the most reliable days of the week. For all the days of the week except Saturday and Sunday, PM peak values are lower than AM peaks. Moreover, PM peak results are higher than MD peaks period. The difference between the days of the week



performance is not very significant, comparing one with each other. However, there is a clear difference between weekdays and weekends. Weekend performance is more stable and reliable than weekdays. Weekends have less variability between maximum and minimum values.

Comparing Saturday and Sunday, the performance is slightly better for Sundays comparing the three different time periods. Moreover, the mean results for AM peaks periods are lower on Sundays. The schedule is so generous that some results are negative, making the mean lower than the rest.

Generally, comparing outbound with inbound performance, there is a difference in the results obtained for MD and PM periods during weekdays. The outbound performance is higher than the inbound. Similarities regarding, as seen for the inbound performance, PM peak values are also higher for all the weekdays if are compared with MD hours.

The most regular and reliable days of the week are Wednesdays and Fridays. However, they are not more reliable than weekend day's performance, where the results shown are almost as those for the inbound direction.

Regarding route 60, the service behavior along the days of the week is different comparing week days and weekends.

The service performance is relatively worse during the weekend days than the rest of the days of the week. However, for weekend days, the differences between peaks are smaller than for the days of the week and mean values are similar for each period. Hence, the performance for weekends is more stable. The differences between maximum and minimum values are lower than during weekdays for all three periods of the day. During weekdays, the performance improves until Fridays, where the service reliability decreases. A small distinction is seen in the service performance over different periods of the day. The most reliable range is the MD, followed by the PM period and subsequently by the AM, which is the one with worse performance. These differences are almost no noticeable. Usually the service behavior is very stable; the range of maximum and minimum values is small.

There is no distinction between inbound and outbound services.

7.4.2 Comparison of routes

Along its 20km the 555 route, from Brisbane CBD to a major southern suburb, contains links of high interest for certain sectors of users, characterizing it by a large influx of passengers. Most of these users make use of public transport during peak hours for both the AM and PM



periods. For this reason, the performance of the service in these ranges of time is worse than the rest. Yet, it cannot be appreciated worse service reliability during peak hours for route 60.

It is understood that the greater number of passengers going in and out of the city, the more traffic and therefore the less reliable service.. This is well reflected in the results of the analysis. Although the range of result's values is narrow between different periods of the day, higher values for the periods of the peaks than for between peak hours are shown. For this reason, the AM and PM periods are those with worse reliability. In the Inbound PM period, the behavior is very similar to MD period, because there is less density of vehicles on the roads and the service operates with greater reliability.

The variability of demand and traffic characteristics, during the course of the day, generates totally different results. Sometimes the bus takes the empty service, without having to stop at all stops. In other circumstances, the bus has to stop, at every stop.

Route 60 is a particular service that takes people from one end of the CBD to the other. In particular, from West End, one of the city's busiest neighborhoods of Brisbane, to the city center, where offices, shops and leisure facilities can be found. The city is more congested and public transport is worse during certain times of day, particularly during peak hours. But, the fact of belonging to a route influenced by traffic signals and operating with passenger for most of the day does not provide much variability in the performance results.

Route 555 inbound and outbound performances can be differentiated, while for route 60 the direction distinction is not of importance. The performance for route 555 is different depending on inbound and outbound directions. Whereas, for route 60, which has also two established directions, the performance is influenced by the use and circumstances of the services. Very similar results were obtained on each direction.

Service reliability trends for each route are different if the analysis is focused in the days of the week performance. Weekends are more reliable than the weekdays for route 555. The service reliability improves along the week for both routes. However, for route 60, Fridays have worse performance than Thursday. Moreover, route 60 has worst performance during the weekends, unlike route 555.



The service reliability offered by both routes is different. Since the route length has been taken into account, the routes can be compared directly. Route 555 is less reliable than route 60. There is a significant difference in peak hour results for each route.

7.4.3 Stop passenger's boarding

An analysis of the mean and standard deviations of the number of passengers boarding at each of the stops of the line was conducted.

Stop Number	1	2	3	4	5	6	7	8	9	10	11	12
Mean	1.4	2.7	3.1	0.2	3.7	2.4	3.4	6.9	2.7	3.1	0.4	0.2
SD	2.2	2.7	2.9	1.5	4.1	2.2	3.2	6	3.8	4.5	1	0.5

Table 14. Mean and Standard Deviation for boarding passengers in route 60 inbound stops.

Stop Number	1	2	3	4	5	6	7	8	9	10	11	12
Mean	5.6	3.5	3.1	2.2	2.9	6.3	4.4	1.4	0.2	0.1	0.2	0.01
SD	8.6	3.3	3	2.1	2.8	4.8	3.7	1.7	0.6	1.1	0.5	0.1

Table 15. Mean and Standard Deviation for boarding passengers in route 60 outbound stops.

Stop Number	1	2	3	4	5	6	7	8	9	10	11
Mean	8.9	7.4	1.1	3.8	0.8	1	0.5	0.5	0.4	0.5	0.3
SD	7.8	5.8	1.7	3.9	1.8	1.8	1	1.1	0.8	1.3	0.8

Table 16. Mean and Standard Deviation for boarding passengers in route 555 inbound stops.

Stop Number	1	2	3	4	5	6	7	8	9	10	11	12
Mean	4.6	1.3	3.8	2.8	3.1	1.6	0.4	0.6	1.8	3.6	0.8	1.1
SD	5.6	2.1	3.9	3.7	3.9	1.9	0.8	2.3	2.5	3.7	1.3	1.7

Table 17. Mean and Standard Deviation for boarding passengers in route 555 inbound stops.

Considering the information that can be extracted from the boarding of passengers at each stop, can be analyzed the mobility study and flux matrices for the bus lines considered.

As highlighted route 60 stop 8 and 6 with higher mean, for inbound and outbound respectively. The two stops are actually the same, namely the Central Stop, one of the four stops belonging to the city center.



With regard to Route 555, stops mean more passengers are Loganholme Elisabeth Station for Inbound and Outbound for 82 street stop. Both are the first stop of the line in each direction.

As for the standard deviations, are high in some cases, due to the large difference between maximum and minimum.







8 ECONOMIC VIABILITY

The following financial budget estimation details the total cost of the elaboration of this master thesis.

The budget is divided into work (hours) dedicated to research and prepare the thesis and the amortization of the tools used during the elaboration of it.

The main cost of this project are the amount of hours needed to understand the tools used, the public transport concepts and to elaborate the calculations to analyse the results. The tasks are basically engineering, except for the writing of the report. The hourly rate of the work done, has been calculated considering that a student who is currently studying the course of Industrial Engineering has a 10 € / hour base salary within the current School Agreement.

The tasks elaborated can be divided as follows:

- Research (Literature review and transport reliability understanding and Self-learning)-120h
- New measure elaboration (considering and elaborating the formula elements)-120h
- Obtaining results using MATLAB-120h
- Results analysis-50h
- Writing the thesis report-80h
- Meetings (3 hours a month meetings)-18h
- Lectures (attending to 10 lectures)-20h

Moreover, the financial budget also includes the amortization of the tools that have been used for the thesis elaboration. This is especially intangible assets (licenses computer) as well as tangible goods (various office supplies). Since the thesis was made in a 6 months period, the depreciable assets are calculated with the proportional cost.

The depreciable assets for the project are:

- MATLAB R2013B License, (Student version with 100€ of annual cost maintenance.)
- Microsoft Office 2013 License (Unlimited use and 100€ cost. 4 years amortization).
- HP Computer (Cost of 1000€, 5 years amortization).

The following Tables 18-20, summarizes the costs taken in the development of services and the cost of each one:



Concept	Amount of time (hrs)	Cost (€/hr)	Total (€)
Engineering		10€/hr	
Research	120h	10	1.200
New measure elaboration	120h	10	1.200
Obtaining results using MATLAB	120h	10	1.200
Results analysis	50h	10	500
Writing the thesis report	80h	10	800
Meetings	18h	10	180
Lectures	20h	10	600
TOTAL			5.680

Table 18. Engineering costs of developing this project.

Concept	Initial cost	Amortization timeframe	Annual amortization (€/year)	Amortization cost (€)
Amortization Elements		10€/hr		
MATLAB R2013B License	100€/year	1 year	100	50
Microsoft Office 2013 License	100€	4 years	25	12,5
HP Computer	1500€	5 years	300	150
TOTAL				212,5

Table 19. Amortization costs of the elements used to develop this project.

Concept	Cost (€)
Engineering Cost	5.680€
Amortization cost	212,5€
TOTAL	5.892,5€
Tax rate (21%)	1.237,452€
TOTAL after tax	7.129,925€

Table 20. Total cost after tax of carrying out this master thesis.

The total cost to develop this thesis, after taxes, would approximately be 7.129,925€.



9 ENVIROMENTAL CONSIDERATIONS

The use of new technological tools (GPS tracking, Smart cards,...), improves the study and analysis of the reliability of public transport. For this reason, improved public transport service provided by the cities, generates a direct improvement to society, since the negative externalities from transport are reduced.

The main negative externalities of transport include:

- Congestion: The externality occurs because each user, when making the decision to use a road, only takes into account the cost it incurs the time they will use on the trip, plus the monetary cost of a vehicle, but do not applauds the fact that the car is reducing fluid traffic for all users. Therefore, the last user who enters a congested road is imposing a cost in terms of extras at other cars on the road that the user does not pay time.
- Air and noise pollution.
- Accidents: A portion of the costs generated goes directly to the people involved (personal injury and vehicle) itself and sometimes have to pay to third parties (through compensation or insurance contracts), there are additional costs that are impose on society as a whole.

The bus, in addition to promoting a peaceful and enjoyable way to travel, largely avoids traffic congestion, jams and possible errors caused by a lack of knowledge of the area. The systematic and widespread use of private vehicles collapses cities and makes it dirty and noisy. A traffic problem that harasses, the streets and monuments progressively deteriorates, lack of parking spaces come together to meet the demand for private car users.

The use of public transport means the caring for many of the movements that are made within the urban alternative. Private transportation generates high levels of CO2 emissions having a high responsibility for climate change and the problems that flow from it and increasingly are citizens. Pollution is expensive, representing 1% to 2% of GDP in developed countries. The private vehicle consumes three times more energy and produces three times more greenhouse gas greenhouse public transport.



In addition, the need for infrastructure generates a high ecological degradation significantly damaging the quality of life of people by air and noise pollution they generate, this being a detrimental element in the health of citizens.

In large cities, where the rate of motorization and private vehicles is high, these externalities play a very important role. It is required continuous analysis and improvement of public transport routes to increase the service and promote the use of it.



CONCLUSIONS

General

Prior to the election of a method for the analysis of public transport in Brisbane, was studied the public transport reliability for buses performance. There were introduced the service reliability definitions, it was realized the attribute's description and the analysis of the indicators traditionally used. In conducting the study, it was determined that much remains for improvement and to determine more accurate indicators of reliability. For this reason, it was decided to create a more complete indicator, which incorporated attributes of the two parts of the service, demand and supply side. None of the indicators analyzed in this research were as complete as the new proposed measure.

The difficulty was to have enough information to get results. There was no problem thanks to Translink, which provided data from GPS and Smart Card to The University of Queensland. The data provided had information on two types of via totally different, which allowed to compare the performance of diverse scenarios.

The data was tested with different indicators, to compare which one was more suitable to continue with the case study of Brisbane city. The new developed measure was elected and so the study was conducted, testing the service performance in each of the routes to draw conclusions.

Implications for this method

The concern with the impacts of reliability on operation efficiency for operators, as well as service effectiveness for passengers, brought about the need to identify and develop meaningful and consistent indicators of reliability in bus transit. This study focuses on passenger-oriented measures, which are believed to be more reasonable to quantify service reliability. The ultimate objective of this research was to develop a measure that could quantify passenger experienced reliability using operational data.

Assessing current reliability measures relationship in identifying service reliability and identifying the most appropriate measure.



- New measure can reflect passenger's perception as it does not only include travel time factors calculations, but also includes waiting time distribution elements to calculate the service reliability.
- Based on the experience it follows reasonable trends. All the procedures followed on the calculations make sense. Moreover, it includes different factors that can reflect more accurately the service reliability. It can detect some performance differences that other measures can't do.

Analyzing travel time reliability for public transport using data from GPS and Smart card systems collected for 6 months in Brisbane, Australia.

- Service performance on weekdays has different reliability than that on weekends. Monday was found to be less reliable than other days.
- The three periods of the day considered have different performances, because of variations of passenger demand and traffic flow. The best service performance occurs between peak hours. Comparing both peaks, the performance is better for PM than for AM peak, because passenger's travel planning is higher during off-work.
- There are different trend performances for the inbound and outbound services. Depending on the direction, the characteristics of the route can vary, hence, affecting the service performance along the whole line.
- The service reliability offered by both routes is different. Route 555 bus way is less reliable than route 60, contrary to supply side intuitive thinking. From surveys, passengers give better service rates to higher frequency bus routes. Thus, as route 60 has lower headways, waiting time is lower than for route 555.



FUTURE RESEARCHES

This section presents studies related to the continuance of the research undertaken, that could be made in the future.

Operational studies could be done. The work shown in this research, could be used to analyse more routes. It would be necessary to have GPS and SmartCard data to assess the performance in different route networks. It would allow to determine the service reliability performance and travel behaviour to define strategies.

In relation to transport planning, it could be used the proposed measure to verify the influence of different strategies, to improve the reliability of service in each scenario. Analysing travel times and passenger patterns in different times of the day for other routes as it has been done in this research. The measure could be used to test the influence of strategies, in order to develop and improve the service performance. To analyze how strategies influences on the service reliability and see if are efficient or not.

Modelling the movement of vehicles and passengers in time and space in public transport systems is generally a rather difficult task. It has to be known the reliability performance, the causes that produce them and the measure used, to model the relation between causes and performances. The new measure could be used to study the influences of different causes on reliability, creating a mathematical model that provides information of the service performance depending on different conditions.





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