Master of Engineering (Civil)

ENGR9700 – Master's Thesis

BCA Assessment of Public Transport Alternatives for the Modbury Corridor Adelaide

Submitted by **Daniel Pece**

Supervised by **Dr. Nicholas Holyoak** and co-supervised **Branko Stazic**

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Glossary of terms and abbreviations

AADT: Annual Average Daily Traffic

BCA: Benefit-Cost Analysis.

BCR: Benefit/Cost Ratio

B (used in tables): Benefits.

C (used in tables): Costs.

Boardings: Are the entry of passengers onto a TU. It differs from Trip, which may include several boardings.

Bus: a generic Transit Mode with ROW-C, run by normal bus and Short-haul/City transit Type of Service.

BRT (Bus Rapid Transit): a generic Transit Mode with ROW-A or ROW-B, run by normal Bus or Guided-Bus, and City Transit-Accelerated/Express Type of Service.

Co (Capacity): is the maximum amount of passenger that can be transported per time unit by a transit line.

CC: Capital Costs, also referred to as investment costs.

Cv: Crush Capacity, amount of passengers that can fit in a Transit Unit.

Capital Costs: Costs incurred during the construction of the project that can be considered one-time expenses.

Car Occupancy Rate: Average amount of people travelling in a car.

CBD (Central business district): Central area of the city, Adelaide in particular.

Corridor (or Transport Corridor): Area, with a linear shape, reserved or dedicated for efficient transport projects.

dP / dPt: Daily Patronage / daily Patronage in year t.

Diversion (or Trips Diversion): Amount of trips or travels that change in modes of transport between the Base Case (without the initiative) and Project Case.

Discount Rate (r): is the interest rate applied to discount Benefits-Costs in Present Value analysis.

Ex-Ante: Evaluation performed before a project is executed, based on forecasts.

Ex-Post: Evaluation performed after a project was executed, based on records.

Four Step Process: A traditional method to model the travel demand in a network. Steps are: Trip Generation, Trip Distribution, Mode Choice and Route Assignment (McNally, 2000)

fm: Max. frequency, the maximum number of TU per time unit that can operate in a transit line.

Heavy Rail: a generic Transit Mode with ROW-A or ROW-B, run by Train Cars, and City Transit-Accelerated/Express Type of Service.

ICE: Internal Combustion Engine

IVT (In-Vehicle Time): Time spent in a vehicle to make a trip or travel.

Light Rail (or Tram): a generic Transit Mode with ROW-A or ROW-B, run by Street Cars, and Short-haul/City transit/Accelerated Type of Service.

Macro Model (or Macroscopic Simulation): A type of model created to simulate and predict traffic in a transport network, generally used in big scale networks (such as a city), working with time steps, where traffic is treated like a compressible and moves forward section by section until eventually exits the system. (Newell 1993; Daganzo 1995; Ni and Leonard, as cited in (Ni, 2006)).

MASTEM: Metropolitan Adelaide Strategic Transport Evaluation Model is a Macro Model developed in software Cube Voyager for medium to long-range strategic transport planning in the metropolitan area of Adelaide (Nicholas Holyoak, 2005).

Meso Model (or Mesoscopic Simulation): A type of model created to simulate and predict traffic in a transport network, generally used in medium-scale networks (such as a corridor). Similar to a Macro Model, works with time steps but traffic is treated as discrete particles governed by pre-defined local rules. (Van Aerde 1995; LANL 1999 as cited in (Ni, 2006)).

Micro Model (or Microscopic Simulation): A type of model created to simulate and predict traffic in a transport network, generally used in small scale networks (such as one intersection or a network of several intersections). The model works with time steps, traffic is treated as objects with properties (such as reaction times, aggressiveness, and preferences), behaviour (following, lane-changing and gap-acceptance logistics) and driven by goals (origin and destination) (Ni, 2006).

Mode of transport: a transportation system that has certain features distinguishable from other transport modes, such as Car, Bus, Rail, Bike, Walk, etc.

Normal Operating Speed (Vo): Average Travel Time divided Length. Includes Stopped time delay, Approach delay and Travel time delay.

NPV: Net Present Value.

Outlier: is data observed, from a sample of a population, with an abnormal distance from other values (National Institute of Standards and Technology (US), 2021).

Outlier 1.5 IQR rule: A common rule that defines outliers as values lower than Q1-1.5*IQR (first quartile minus 1.5 interquartile range) or higher than Q3+1.5*IQR (third quartile plus 1.5 interquartile range) (National Institute of Standards and Technology (US), 2021).

Pc (Productive Capacity): is the product of Capacity and the Normal Operating Speed (Vo).

Public transport (or Transit): is a type of urban passenger transport with predetermined lines or routes, schedules, fares and accessibility for all people (Vuchic, 2007).

p (used in tables): Passengers or Patronage.

Patronage (Passengers, Ridership or Users): Amount of people using the public transport service.

Ridership: Synonym of Patronage, Passengers and Users.

ROW (Right Of Way): is the categorization of a Transit Way by its degree of separation from the general traffic. It can be Category C (mixed traffic), Category B (longitudinally physically separated) or Category A (Longitudinally, physically and grade-separated. Without grade crossings). (Vuchic, 2007)

SCATS: the Sydney Coordinated Adaptive Traffic System is an intelligent and adaptive control system for traffic intersections (SCATS-NSW Government, 2021).

sps: Spaces available in a TU (Transit Unit).

System Technology: Several features of a Transit System related to its technology, such as its support (rubber tire/steel wheel), guidance (steered/guided/externally guided), propulsion (diesel ICE/gasoline ICE/electric Motor), control (visual/signal/fully automatic). (Vuchic, 2007)

Station (or Stop): location dedicated for Transit Units to stop for the board and deboard of passengers.

Street Car: a type of Transit Unit generally comprised of several transit vehicles (smaller than Train Cars), with steel wheels, guided by rails, powered by an electric motor and visual control.

Train Car: a type of Transit Unit generally comprised of several transit vehicles (bigger than Street Cars), with steel wheels, guided by rails, powered by an electric motor and signal/fully automatic control.

TTp/TTip/TTop: Sum of Travel Times spent by car (TTC) or transit (TTT) users at peak hours(p)/ inter-peak hours (ip) or off-peak hours (op)

Trip (or Journey): Trip with an Origin and Destination, which can be travelled by Public Transport and may include several boardings.

TT (Travel Time): Time spent to make a travel in a certain mode of transport and a certain route.

TTC: Travel Time for Cars Mode of Transport.

TTT: Travel Time for Transit Mode of Transport.

Type of Service: Classification of the Transit system by type of routes (Short-haul: serving local areas/City transit: serving big areas/Regional transit: long trips), schedule (Local: stopping at all stops/Accelerated service: skips several stops/Express service: widely spaced stops) and time of operation (All day/Peak hour/Irregular). (Vuchic, 2007)

Transit: Synonym of Public Transport.

TU (Transit Unit): Transport Unit designed to carry passengers comprised of one or several transit vehicles travelling as a unit.

Transit Mode: a Public Transport system defined by its ROW, System Technology and Type of Service. (Vuchic, 2007)

Vo: Normal Operating Speed = Distance / Travel Time (affected by delays)

VOT (Value Of Time): Monetary value adopted for IVT.

Way (Transit Way or Travel Way): is the travel area on which transit units operate. (Vuchic, 2007)

Executive Summary

This Thesis aims to generate and evaluate Public Transport Options for the Modbury corridor in Adelaide, where the O'Bahn (a guided-busway semi-rapid system) was constructed. In order to do so, two types of evaluations are performed, transit performance evaluation and economic BCA evaluation.

For this sake, this report starts with an introduction, setting the background, justification and objectives. Then continues with a literature review, examining the relevant theoretical background.

Thereafter, the Transit Mode options are developed and evaluated from the performance point of view.

At this point, before continuing with economic considerations, the Benefits, Costs and impacts not considered are defined.

The following two chapters aim to Model the transport network to obtain Volumes parameters and Travel Time parameters for Benefits and Costs calculations.

Furthermore, the evaluation parameters are defined, followed by the Benefit-Cost Analysis results with a discussion of them. The following chapter compares the results with the Transit Modes performance parameters.

Finally, the conclusions and future research possibilities are reflected, where the main conclusions were that the three most important components affecting the BCA are the Transit Capacity because it defines its feasibility, Capital costs and Travel Time saving at peak hour because are the most relevant components in NPV and BCR.

Moreover, the Guided-Bus Rapid Transit is considered the best option from an economic point of view, for the expected demand growth in the next 30 years. Similar to the conclusions formulated in past evaluations, for the past 30 years, before the O'Bahn was constructed. Indeed, the O'Bahn produces a positive NPV in all evaluation considerations, which is considered rare for transit services. Even if the demand would grow more than expected, the Guided-BRT, or the current O'Bahn, is still the best option and still feasible as long as the performance is improved accordingly.

Acknowledgements

I wish to thank Professor Derek Scrafton, from the University of South Australia, for his valuable support in revising the parameters adopted, providing past evaluation reports of the Modbury Corridor, sharing his experience and checking important values with other experts, such as Dr. David Bray and Dr. Peter Tisato. Equally important, I want to thank my supervisors, Dr. Nicholas Holyoak and Branko Stazic, for providing excellent literature and their support in defining the best practical solution for many difficulties faced throughout the research, such as data collection, survey, model calibration and validation. Finally, I thank Arch. Lorena Jurado for her support in Urban Planning matters and logistic matters during surveys.

1. Introduction.

This is a Master's Thesis for Master of Engineering (Civil) at Flinders University. The course had a duration of two years and the topic worth 18 Units over a year.

This Thesis consists, in summary, of a Benefit-Cost Analysis on different Transit Mode options for the Modbury Corridor in Adelaide (South Australia). In order to do so, different Transit options were analysed, such as Bus, BRT, Light Rail and Heavy Rail. The Transit Mode options were tested in Different scenarios measuring their sensitivity.

A considerable effort of this thesis was dedicated to determining the input parameters for the evaluation, and the evaluation was performed Ex-Post for the existing project and Ex-Ante for potential future options.

1.1. Background

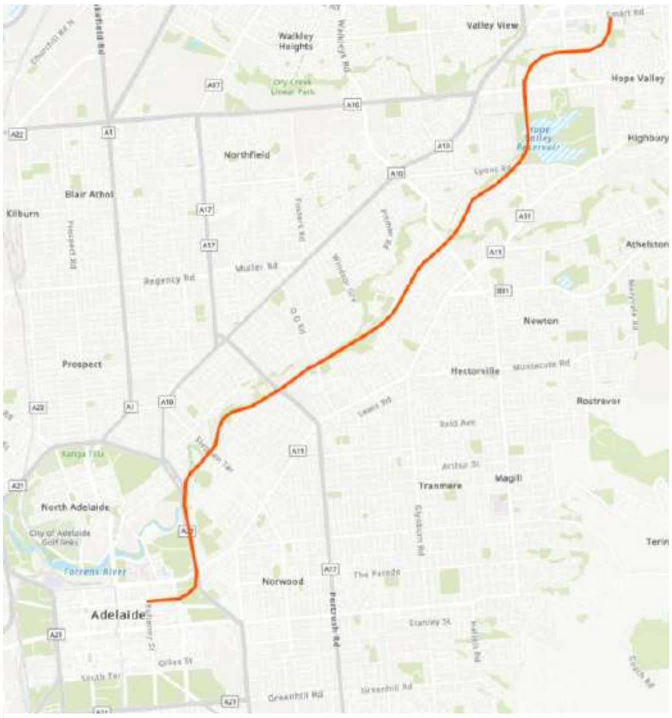

Figure 1-Sketch of the O'Bahn extent.

The Modbury corridor extends from the North-East of the CBD (Grenfell St. & East Tce.) until Tea Tree Plaza Interchange, located in Modbury (North East suburb in Adelaide).

It is currently run by the O'Bahn, which is a type of Guided-Busway system with 33 different bus service routes using the infrastructure (Adelaide Metro, 2021), and approximately 31.000 daily boardings (Government of South Australia, 2017, as cited in (Scrafton, 2019)).

Refer to Annex A for more details of the Bus routes using the O'Bahn.

The system started to operate in 1986 for Stage one (Klemzig Interchange and Paradise Interchange), then stage two (extended to Tea Tree Plaza Interchange) in 1989/1990, and continues to provide service at the present day. In addition, a tunnel for a quicker access to the CBA Area, among other relevant objectives, was constructed between 2015 and 2018. The buses operating in the O'Bahn have horizontal wheels to be used as guides in the guided-track as shown below:

[figure removed due to copyright restriction]

Figure 2- Views of the Adelaide O-Bahn (with initial use of Mercedes-Benz buses) (Wayte and Wilson (1988) as cited by (Scrafton, 2019).

1.2. Justification

In Adelaide, South Australia, the public transport system is comprised of buses, rail (trains), light rail (trams) and it is considered that public transport connectivity and accessibility is crucial to enhance the liveability and wealthiness of cities (Infrastructure Australia, 2018). Indeed, the transport infrastructure investment in Australia is currently close to record levels, especially by the public sector and it is expected that the public transport crowding will grow around 500% by 2031 (Infrastracture Australia, 2019).

This can be seen in several recommendations stated in the Australian Infrastructure Plan, Priorities For Our Nation's Future, such as improving public transport capacity and frequency across all modes (recommendation 3.1), adopting an agnostic approach for funding (i.e., to prioritize benefits rather than risks) (Infrastructure Australia, 2016). Moreover, one initiative from the Infrastructure Australia Priority List 2020, is to expand the Adelaide tram network (Infrastructure Australia, 2020).

Similarly, the South Australia Integrated Transport and Land Use Plan, and Infrastructure SA's 20-YEAR STATE INFRASTRUCTURE STRATEGY propose many challenges related to mobility and prioritizing solutions relying on public transport improvements and upgrades (Government of South Australia, 2013) (Infrastructure SA, 2020).

In this context, it is important to understand what different options of Transit Modes are currently available, their main features and performance properties. That's why part of the research was conducted in this regard to classify the most common Transit Modes, such as Bus, Light Rail, Heavy Rail and, particularly, the O'Bahn, which is a type of BRT. In addition, research was conducted to determine their properties and performance indicators.

Furthermore, it is necessary to understand what types of evaluation methods exist and, in particular, economic evaluation methods, such as Benefit-Cost Analysis (BCA), to quantify the benefits of each option.

Though this analysis is common practice when planning Transit projects, it is much less common to perform Ex-post analysis. In other words, re-evaluate the performance of a project already implemented. Thanks to having access to Evaluation Reports of the Modbury corridor in the planning phase, provided by Professor Derek Scrafton (University of South Australia), research was conducted to re-evaluate the O'Bahn project.

It is equally important to perform a technical-performance evaluation of potential Transit Mode options, along with economic evaluations of these options for the future of the Modbury Corridor.

In addition, this research may ease the planning and evaluation process of similar transit projects initiatives.

1.3. Aims, Objectives and Scope

The Aims of this thesis are:

a) Generate Transit Mode options for the Modbury corridor, characterize its technical and performance properties, and compare them.
b) Perform a quantitative Benefit-Cost Analysis (BCA) Ex-Post of the current O'Bahn project. And to perform a BCA Ex-Ante of the potential options generated for future scenarios.

In order to fulfil these aims, several specific objectives were set. Each of the following chapters seeks to fulfil the following objectives:

- Research the state of the art in regards to Transit Modes technical and performance classification. Research transit evaluation methodologies and define the most suitable BCA methodology for this thesis. Study the background information and past evaluations of the O'Bahn project. (Chapter 2 – Literature Review)
- Prepare a list with different options a potential Transit Modes for the Modbury corridor. Describe its characteristics. Calculate their performance. Estimate their Capital Costs. Compare the options. (Chapter 3 – Options Generation and Classification).
- Define Benefits and Costs to be evaluated.
- Determine Transit Patronage and Car Volumes in adjacent Arterial Roads (which are affected by trips diversion to Transit). Determine their yearly, weekly and hour-direction distribution. Calibrate a model for Travel Times estimation as a function of the volume. Validate model with surveys. Calculate Travel Times in different scenarios, differentiate between Peak, Inter-Peak and Off-Peak hours, so Travel Time savings can be estimated. Also, calculate time penalties associated with different modes of transport. (Chapter 5 – Travel Time Estimations).
- Define the evaluation parameters (Evaluation period, Interest rate, Value of time, Option and non-use value, Environmental costs, Car operation costs)

- Estimate project's residual value and Capital Costs overrun risks. (Chapter 6 – Residual Value and Capital Costs overrun risks)
- Evaluate environmental costs and environmental costs savings (Chapter 7 – Environmental Costs Reduction)
- Calculate car operational costs and car operational costs savings (Chapter 8 – Car operation saving)
- Estimate the Option and Non-Use monetary value (Chapter 9 – Option Value Benefits)
- Calculate the Benefits and Costs for all of the scenarios and options defined. Disaggregate Benefits by type and also by peak/inter-peak/off-peak periods. Evaluate and describe the BCA results. (Chapter 9 – Benefit-Cost Analysis Results)
- Formulate Conclusions and recommendation. (Chapter 10 – Conclusions and Recommendations)

2. Literature Review.

This chapter aims to put in context the state of the art in regards to Transit Modes technical and performance classification. Thereafter, to research transit evaluation methodologies and define the most suitable BCA methodology for this thesis and finally study the background information and past evaluations of the O'Bahn project

2.1. Transit Modes

Modes of Transport, in general, can be classified by type of usage as shown below:

[figure removed due to copyright restriction]

Figure 3-Classification of urban passenger transportation by type of usage (Vuchic, 2007)

Furthermore, Transit Modes, which are Public Transport systems, are defined by their Right of Way, System Technology and Type of Service (Vuchic, 2007). An overview of Transit Modes definition and characteristics is presented below:

[figure removed due to copyright restriction]

Figure 4-And Overview of transit mode definition, classification, and characteristics (Vuchic, 2007)

As it can be seen in the figure above, the three basic characteristics will define a transit mode. However, some of the characteristics do not need to be rigidly fixed. To exemplify, the most important types of Modes of Transport in Adelaide are described below:

Car: is a private use transportation type, using mixed traffic streets.

Taxi/Uber/dial-a-ride type: is a for-hire transportation type, using mixed traffic streets.

Regular Bus: is a public transportation type (or Transit), using mixed traffic streets (Right of Way C), with rubber tires, steered guided (by the driver), visual control, diesel ICE, and Short-haul or city type of service.

O'Bahn Bus (outside the O'Bahn): O'Bahn buses are Regular buses outside the O'Bahn, but BRT buses when entering the O'Bahn.

O'Bahn Bus (using the O'Bahn – BRT): is a public transportation type (or Transit), using exclusive lanes longitudinally and grade-separated from general traffic (Right of Way A), with rubber tires, externally guided (with horizontal rubber tires supported by the guided track's kerbs), visual control, diesel ICE, and express type of service.

Tram: is a public transportation type (or Transit), using exclusive lanes longitudinally separated from general traffic (Right of Way B), with steel wheels, guided (wheel flanges-rail interaction), visual control, electric motor, and short-haul or city type of service.

Train: is a public transportation type (or Transit), using exclusive lanes longitudinally and grade-separated from general traffic (Right of Way A, but some intersection ROW-B), with steel wheels, guided (wheel flanges-rail interaction), signal control, electric or diesel-electric motor, city and express type of service.

2.2. Transit Performance

Furthermore, different Transit Modes will perform differently due to their characteristics. There are plenty of different performance indicators related to Capacity, Productivity, Efficiency, Utilization, Speed, Density, Frequency, Network performance (Vuchic, 2007). The most relevant for this thesis are described below:

Seat Capacity: is the number of seats available in a Transit Unit, expressed in [sps/TU].

Crush Capacity (Cv): is the number of passengers that can fit in a Transit Unit. It is always higher than the Sean Capacity, since it includes, in addition, people travelling standing. It is expressed in [sps/TU].

Normal Operating Speed (Vo): It's the average travel speed from one terminal to the other (for Transit) or (for cars) the average travel speed to travel through a section. Normal Operating Speed is affected by different types of delays, such as Stopped time delay, Approach delay and Travel time delay as illustrated below:

[figure removed due to copyright restriction]

Figure 5-Delays affecting Operating Speed (Vo) (Mathew, 2021)

The orange arrow represents the Normal Operating Speed, and it can be expressed as:

Vo [km/h] = Distance [km] / Travel Time [h]

In other words, even if the instant speed of a vehicle can reach high speed (e.g. Buses in the O'Bahn reach 85 km/h), the Normal Operating Speed is reduced by stops and delays (e.g. Buses in the O'Bahn have an operating speed of 40 km/h due to stops at the stations, acceleration, deceleration, etc.).

Spacing: minimum space required between TU, expressed in [km]

Max. frequency (fm): the maximum number of TU per time unit that can operate in a transit line. This constraint can be determined by the max. frequency of the way (TU Speed divided Spacing) or the station max. frequency (maximum number of TU dispatched per time unit), whichever is lower (Leurent, 2011). It is expressed as [TU/h]

Transit Capacity (Co) (or simply, Capacity): is the maximum amount of passenger that can be transported by a transit line, and it can be expressed as:

Co [sps/h] = Cv * fm (Vuchic, 2007) & (Transportation Research Board, 2013) [1]

Productive Capacity (Pc): is the product of the Transit Capacity and the Normal Operating Speed. If the Capacity of a transit line is seen as the Force of a transit line, Productive Capacity can be seen as the power of a transit line (based on similar analogies by (Vuchic, 2007)). It can be expressed as:

Pc [sps-km/h-h] = Co * Vo [2]

Way Linear Density (D1): Is the Transit Capacity divided by the Normal Operating Speed:

D1 [sps/km] = Co / Vo [3]

Way Density (D2): is the maximum amount of passengers that can travel per unit area in a Transit Way. It can be expressed as:

D2 [sps/ha] = D1 / w (width of the way) [5]

All of the above parameters needed to be determined for the Transit Mode options, and that is the reason why several documents were researched to determine the most accurate values for Adelaide Transit modes, and also potential upgrades.

Several parameters were found in the Transport Modelling Report for Adelaide (Veitch Lister Consulting, 2019), which is a report of a Macro Model of the Adelaide Transport system. The main parameters found were the Seat and Crush Capacity of Transit Units of Adelaide Transit Systems. In addition, these parameters were compared with technical specifications of the most common Transit Unit vehicles used in Adelaide, which are:

- Diesel-Electric Train: 3000 class rail car (DPTI, 2018)
- Tram/Light Rail: As specified in Transport Modelling Report for Adelaide (Veitch Lister Consulting, 2019)
- Electric Train: Adelaide Metro A-city 4000 Class (Metro Report International, 2019)
- Bus: Scania K320UB 4×2 Custom CB80 (ACT Bus, 2014)
- Articulated Bus: Scania K360UA 6×2_2 CB80 (ACT Bus, 2012)

Moreover, other available parameters in the Veitch Lister Consulting Report, such as the Value of In-Vehicle-Time (IVT), growth rates, Crush Capacity, Max frequency, Normal Operating Speed of Bus at Peak and Off-Peak hours, etc., were contrasted with the adopted values for this thesis, showing consistency and similarity with the values adopted. However, were this report was taken into account only as a reference, because specific data for the corridor, such as O'Bahn routes schedule, Articulated Bus Technical specifications, etc, were considered with higher precedence.

Max. Frequency and Normal Operating Speed were investigated and calculated from Adelaide Metro Timetables (Adelaide Metro, 2020). Either for the O'Bahn, Buses in Arterial Roads, Trams and Trains.

Other systems with higher frequency (and higher demand) were investigated too for estimating how much higher Capacity a Transit Mode Option could offer. Sydney and Melbourne Transit System were looked upon (Transport NSW, 2020) (Public Transport Victoria, 2020).

2.3. Bus vs Rail Modes

Transit Modes can be categorized by Productive Capacity (Pc) and Investment Cost (Co) in three main categories. Street transit (low Pc & Co), Semirapid Transit (medium Pc & Co) and Rapid Transit (high PC & Co) (Vuchic, 2007).

Regular Bus (RB) and Street Car (SCR) are the typical Street Transit. Bus Rapid Transit (BRT, Bus or Articulated-Bus in a busway) and Light Rail Transit (similar to Street Car but higher TU capacity & speed) are the typical Semirapid Transit. And finally, Rapid Transit is typically comprised of Heavy Rail technologies (RRT: Rail Rapid Transit; RGR: Regional Rail). These categories are shown in the chart below:

[figure removed due to copyright restriction]

Figure 6-Relationships between productive capacities, investment cost, and passenger attraction of different generic classes of transit modes (Vuchic, 2007)

In order to reach a high Productive Capacity for Rapid Transit, high TU capacity is required. Therefore, Heavy Rail is suitable for Rapid Transit services (or alternative modes with high TU Capacity like Rubber-tyred metro) because it can operate with big TU comprised of many transit vehicles. However, it will generally be a good option as long as the demand is very high (Alejandro Tirachini, 2009).

Then, for Semirapid Transit or Street Transit, Bus and Light Rail technologies are both very competitive. Generally, the best option will depend on the specific characteristics of the route and its objectives. In short, both Technologies have (relatively) positive and negative aspects, and its best described by the following summary from “Evaluating Public Transit Benefits and Costs – Best Practices Guidebook” (Victoria Transport Policy Institute, 2020, p. 88):

[figure removed due to copyright restriction]

Figure 7- Summary of Rail Versus Bus (Victoria Transport Policy Institute, 2020)

As a conclusion in this regard, after reviewing many references, It can be argued that Light Rail technologies are more expensive (higher Capital Costs & Operational Costs (Bray, 2010)), hence producing lower NPV or BCR compared to Bus alternatives (Alejandro Tirachini, 2009). Nonetheless, Rail technologies can be considered “Premium” services (greater comfort, attraction, reliability, etc. (Victoria Transport Policy Institute, 2020)).

2.4. Adelaide Public Transport System Background

Adelaide Metro is Adelaide's public transport system, run by the Department for Infrastructure and Transport (DIT), which is a department of the South Australian Government.

The operation of Buses, Trams and Trains, is divided by city areas and are operated by private operators :

- Keolis Downer operates the Train Lines.
- Buses (including O'Bahn) and Trams are operated by Torrens Transit, Torrens Connect, SouthLink and Busways.

The total patronage of public transport services (which is always a little bit more than the total trips by Public Transport), for the period 2018-2019 was roughly 76.000.000 (seventy-six million) trips.

Table 1 - Adeliade Metro, Total patronage by mode (Department of Planning, Transport and Infrastructure, 2019)

Bus	Tram	Train	Total patronage*
51,056,799	9,448,561	15,653,849	76,159,209

In this context, the Department for Infrastructure and Transport (DIT) is the owner of the transit system, and responsible for funding, investment, project development and management.

Users can access Public Transport with a Metrocard, which is an electronic smart card of the ticketing system. The fares are the same for every Transit Mode but there are many types of fares: Peak trip, Interpeak Trip, and 3/14/or/28-day pass. Additionally, fares have a different rate for Regular commuters, Students, Seniors and Concession (Metro Adelaide, 2020). This is why the Average Fares in the whole system (based on Fare revenue), estimated by Dr David Bray (Bray, 2013), are the most suitable to use.

2.5. Evaluation Methods

Many guidelines, manuals and research jobs were investigated in order to understand what is the most suitable methodology to be applied when evaluating different Transit Mode options. The references taken into account to define the methodology were:

- ATAP (Australian Transport Assessment and Planning) Guidelines (Transport and Infrastructure Council, 2018).
- Assessment Framework for Initiatives and Projects to be included in the Infrastructure Priority List (Infrastructure Australia, 2018).
- Project Business Case Evaluation Summary of many transport projects in Australia (Infrastructure Australia, 2020).
- Guidelines for the evaluation of public sector initiatives (Government of South Australia, 2014)
- Manual for Economic Evaluation of Public Transport Projects (Government of South Australia, 1980)
- Cost-Benefit Analysis Manual – Road Projects (Transport and Main Roads (QLD), 2021).
- Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives (Transport for NSW, 2016).
- Evaluating Public Transit Benefits and Costs – Best Practices Guidebook (Victoria Transport Policy Institute, 2020).
- A new evaluation and decision making framework investigating the elimination-by-aspects model in the context of transportation project’s investment choices (R. Khraibani, 2016).
- Evaluating the impacts and benefits of public transport design and operational measures (Masoud Fadaei, 2016).
- Influence of reference points in ex post evaluations of rail infrastructure projects (Nils O.E. Olsson, 2010).
- Performance evaluation of public transit systems using a combined evaluation method (Chunqin Zhang, 2014).
- Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach (Cathy Macharis, 2014).
- Transport investment and economic performance: Aframework for project appraisal (James J. Laird, 2017).

- Ex-post Economic Evaluation of National Road Investment Projects (Commonwealth of Australia, 2018)

As a result, a Detailed Benefit-Cost Analysis (BCA) method was selected, in accordance with ATAP Guidelines (Transport and Infrastructure Council, 2018). Even though many other evaluation guidelines and research projects propose the same methodology, the ATAP Guidelines is selected as the main reference because provides general values for Australia in general and also is the most comprehensive. This methodology is best suited to evaluate and select the optimal transport initiative option before progressing further to a more detailed engineering design. In other words, as it is framed in the following figure, BCA should be applied in the stages of wider engineering issues to narrow options down to one specific project:

[figure removed due to copyright restriction]

Figure 8-Scoping a transport network problem (Austroads, 2014)

There are two types of BCA (or CBA) methods, Financial-BCA and Economic-BCA. The Financial-CBA is calculated with the cash flow (effective monetary costs and benefits) of the project and is intended to estimate its financial suitability. On the other hand, the Economic-BCA also takes into account the contribution of the project to the economy and wellbeing of the society, using economic values (or shadow prices, which express the value that society is prepared to pay for the impacts) (FAO, 2020). Furthermore, the E-BCA can be extended to include Social and Environmental considerations using economic values (or shadow prices) (NEF Consulting, 2020). This type of Economic-Social-Environmental BCA is the methodology mostly applied to transit projects and transport projects in general in the phase of planning, therefore this thesis is focussed on the E-BCA, simply referred as BCA. Moreover, the BCA can be applied in different stages of the project cycle, being Ex-Ante (before the project implementation), Intermediate (somewhere halfway the implementation of the project) and Ex-Post (at the end of the implementation of the project) (FAO, 2020).

BCA is a standard methodology applied all over the world and on a wide range of projects, it aims to summarize, in monetary values, all the gains (Benefits and savings) and losses (Costs) produced by a project to all the affected members of the society (Transport and Infrastructure Council, 2018). The net sum of benefits minus costs are expressed in a single measure, the Net Present Value (NPV):

$$\mathrm{NPV} = \sum_{t=0}^{z} \frac{B_t - C_t}{(1+r)^t}$$
[6]

All benefits (B) and costs (C) from period t=0 to t=z are brought to present dollars using a discount rate r.

If the NPV is positive, it means that the benefits exceed the costs and that the project is economically efficient and positive for the society 'as a whole' (although there will be losers and gainers with the project) (Transport and Infrastructure Council, 2018). It is also worthwhile to mention that, according to Dr. Derek Scrafton, an expert in transport planning, it's rare to find Transit Projects with a positive NPV. Indeed, according to Dr. David Bray's work (Bray, 2010), in Adelaide, the operating costs of Transit Services are many times higher than the Fare, requiring subsidies. Moreover, even Economic Social and Environmental benefits (with shadow prices), are not sufficient for the benefits to overcome the costs. Nevertheless, Transit Service is still offered, even with a deficit, due to Transport Policies, such as Improving Accessibility for Communities (Government of South Australia, 2013).

Therefore, the bottom line for a Transit Project initiative is to have an NPV higher than the base case, as long as objectives such as 'to provide accessibility' are fulfilled.

Another relevant indicator is the Benefit-Cost Ratio (BCR):

$$BCR = \frac{|PV\ [Benefits]|}{|PV[Cost]|}$$
[7]

Which shows the ratio between the Benefits to Cost. A BCR higher or equal to 1.0, means that the project will deliver a positive NPV (i.e. that the benefits outweigh the costs).

Finally, there are two ways of calculating Present Values, using Nominal Discount Rate or using Real Discount Rate. The first one uses nominal Benefits-Costs with nominal Discount Rate, and then should be adjusted by effects of inflation. While the second one uses Real Benefits-Costs measured in time 0 dollars and Real Discount Rate (Scott, 2020). The difference between the two methods can be expressed with the following expressions, which is the Fisher Effect Equation:

$$1+i = (1+r) \times (1+\pi) \quad ; \text{or}$$

$$r = i - \pi \qquad \text{(an approximation)} \qquad [8]$$

where i is the Nominal Discount Rate, r the Real Discount Rate, and π the Inflation Rate.

It's important to make this distinction, because it implies two different way of taking into account the effects of inflation, and two different rates of return (nominal i, or real r). In general, Projects Evaluation Reports consider a Real Discount Rate of 7%, which is the standard for BCA in Australia (Infrastructure Australia, 2020). However, in Australia in the last 25 years, the Real Interest Rate varied between 1% and 7% (Trading Economics, 2021).

Therefore, the method selected for this thesis is to use Real Discount Rate, with all Benefits-Costs expressed in time 0 dollars (prices in december 2020). Regarding the r rate, two values will be considered, 7% (which is the standard) and 4% (which is based in the last 25 years of Australian Real Interest Rates). An r rate of 10% too is usually applied in Projects Evaluation, but it is considered to be too high for a real interest rate (it may be suitable as a nominal discount rate).

Thereafter, a summary of the steps required to perform the evaluation is listed below (Transport and Infrastructure Council, 2018):

- Specify Base Case and Options
- Identify Benefits and Costs
- Make Demand Forecasts
- Estimate Benefits and Costs
- Calculate Results (NVP, BCR, Risks, Sensitivity, etc.)

2.6. Transit System Costs

In order to determine Costs, there are two different approaches. One is to Estimate the Cost of a project following, for instance, the Cost Estimation Guidance from the Department of Infrastructure, Regional Development and Cities (Australian Government, 2018), which is a very exhaustive method and produce very precise costs, suitable for Construction Price estimation. On the other hand, for earlier stages, such as planning and evaluating alternatives, Cost Benchmarking can produce approximate values, good enough for decision making in the planning stages. The Cost Benchmarking process consists of collecting data (cost data of similar projects), modelling and comparing projects, analysing the costs, and generate project costs indexes (Royal Institution of Chartered Surveyors (RICS), 2011).

This approach was selected to determine Capital Costs, Residual Value, Lifespan, and also Fare Revenue (which is computed as a benefit in the BCA).

The ATAP (Australian Transport Assessment and Planning) Guidelines (Transport and Infrastructure Council, 2018) provides benchmark costs to estimate costs and benefits in Transport and Transit projects. These costs are generally based on recent research (generally no older than 2017) and apply to Australia.

Notwithstanding, Capital Cost is a very important parameter in the BCA. So, an additional Benchmarking iteration was conducted to estimate with higher accuracy the capital cost (and therefore the Residual Value). Infrastructure Australia publishes the Project Business Case Evaluation Summary of major transport projects in Australia (Infrastructure Australia, 2020). Those evaluations present a summary of the Benefit-Cost Analysis, costs which are generally based on Cost Estimation methodology (in contrast to a Benchmark Costing). The Infrastructure Australia database, ATAP Guidelines and O'Bahn real costs records were selected to prepare benchmark costs.

Equally important are the Operational Costs and Fares Revenue. Many guidelines of Operational costs and research production were investigated, such as:

- Estimation of Operating and Maintenance Costs for Transit System (U.S. Department of Transportation, 1992)
- Comparing Operator and Users Costs of Light Rail, Heavy Rail and Bus Rapid Transit Over a Radial Public Transport Network (Alejandro Tirachini, 2009)
- The Financial Cost of Transport in Adelaide: estimation and interpretation (Bray, 2013)
- The Nature of Rationale of Urban Transport Policy in Australia (Bray, 2010)
- ATAP Guidelines (Transport and Infrastructure Council, 2018)

As a result, the cost and fare values from Dr. David Bray's research were considered with higher precedence because are based on the Adelaide Transit System. A summary of the parameters adopted are listed below:

[figure removed due to copyright restriction]

Figure 9-Average financial cost of carrying passengers by public transport in Adelaide in 2006/07 (December 2007 prices) (Bray, 2010)

A Journey (or Trip) has an Origin and Destination, which can be travelled by Public Transport and may include several boardings. On the other hand, the O'Bahn is just a portion of the routes using it, and is generally a fraction of its passenger's Journey. Therefore the Values considered were Cost and Fare per boarding, even if they are not expressed per kilometre (this is because of how the system is operated and charged).

Finally, ATAP Guidelines (Transport and Infrastructure Council, 2018), Life Cycle Cost of Australian Route Buses (Robbie Napper, 2016), Useful Life of Transit Buses and Vans (U.S. Federal Transit Administration, 2007) and The Lifespan of Main Transport Assets (The Geography of Transport System) (Rodrigue, 2020) provide a good reference for defining the lifespan of the Transit Mode options and their Residual Value.

2.7. O’Bahn Project History

In this section, many evaluation reports of the Modbury Corridor are reviewed. In general, the subsequent evaluation reports took into account similar considerations:

- 30 Years Evaluation Period
- A discount rate of: 7% and, as a sensitivity test, 4% and 10%.
- Capital and Operational Costs
- Benefits to existing and diverted Transit Users (Travel Time savings)
- Benefits to remaining Car users (Travel Time savings)
- Savings caused by reduction in car usage (such as reduction in accidents, car operation costs, car ownership)
- Linear depreciation for Residual Value calculation, considering generally between 30% and 40% of the initial cost at the end of 30 Years period.

Other considerations, such as Environmental Costs, Parking costs, Land use impacts, Impacts and effects on the economy, jobs, and health, were generally overlooked whether because of low relevance in VPN and BCR values or because they were out of the objective’s scope.

Indeed, the Modbury corridor started to be evaluated at least since 1974, and the main objectives for this corridor were (Department of Transport (SA), 1991):

- "Increase accessibility between the north-eastern suburbs and the city through significant reductions in jurney times and improved reliability of schedules due to higher speeds and limited stops."
- "Reduce congestion on the existing road network by diverting selected bus services to the new busway route."
- Design a system with "sufficient flexibility to permit adaptation to technological change."
- "Redevelop the River Torrens Valley to create an effective linear park for use by the public."
- "Encourage the development of Tea Tree Plaza as a regional centre and focus for the north-east suburbs."

However, the last two objectives listed would not generate significant transport benefits and it is important to take this into account to understand, for instance, why a Freeway (which would produce better VPN and BCR compared with Transit Options) was not effectively considered as an option.

The oldest available record (courtesy of Dr. Derek Scrafton) of transit options evaluation for the Modbury Corridor is from 1974: Study of Public Transport Alternatives for the Modbury Corridor (Department of Transport (SA) and P.G. Pak-Poy & Associates Pty. Ltd., 1974). By that time, the Modbury corridor was yet unused, and this report evaluated several alternatives of public transport systems, comparing them with not using the corridor. Therefore, not using the corridor (Do nothing) will be the Base Case reference for measuring all benefits (and savings), not only for this thesis but observed in successive evaluation reports of the Modbury Corridor as well. Moreover, in this report (Department of Transport (SA) and P.G. Pak-Poy & Associates Pty. Ltd., 1974), several alternatives were evaluated with a BCA. It would take into account the Capital Costs, Operational Costs, Benefits for the current Transit Users, benefits for the converted (or diverted) Users from the road (cars), benefits for the remaining road users, and two different discount rates. All of this is a standard application of the methodology, yet there are some benefits (such as environmental costs savings) that are overlooked because it's considered to be of low relevance. This is common practice in transport project evaluations, to disregard some of the impacts, because of its low impact in the NPV, or because it's out of scope (Victoria Transport Policy Institute, 2020, p. 8).

In summary, the first BCA of Transit Mode options for the Modbury corridor produced the following results (only the most relevant results are shown):

Table 1-Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1974 (Department of Transport (SA) and P.G. Pak-Poy & Associates Pty. Ltd., 1974).

Transit Mode	B/C Ratio (r =7%)
Heavy Rail	0.45
Light Rail	0.78
Busway	1.00

At that time, the Busway was the one with a better B/C Ratio. However, it is worthwhile mentioning that the patronage was overestimated (Estimation in 1974: 44.000 by 2003; while in this thesis is estimated to be around 27.000 by 2003).

In 1977, another study of the Modbury Corridor was conducted: North East Area – Public Transport Review – Economic Assessment (Travers Morgan Pty. Ltd., 1977). This time, more refinement in the Transit Modes were evaluated, considering different standards of service, and also Traffic car accidents reduction was incorporated. Summary of the most relevant results are shown below:

Table 2- Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1977 (Travers Morgan Pty. Ltd., 1977).

Transit Mode	B/C Ratio (r =7%)
Heavy Rail	0.34
Light Rail	1.00
Busway	0.70

This time, the Light Rail option would produce better results, followed by the Busway option. In addition, this report considered the option of building a freeway in the Modbury Corridor, which produced the best results (BCR = 2.81), but this option was discarded because one of the objectives planned for the Modbury Corridor was to improve the amenity along the corridor (Department for Infrastructure and Transport, 2015), and the space occupied by the transit project was sought to be minimized.

In 1979, a feasibility study of Light Rail was conducted: Northeast Light Rail Line – Economic & Financial Assessment (Department of Transport (SA), 1979). This time, in addition to car accidents reduction, car parking savings were included. Summary of the most relevant results are shown below:

Table 3-Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1979 (Department of Transport (SA), 1979)

Transit Mode	B/C Ratio (r =7%)
Light Rail	1.20

At that point, Light Rail was the prefered option for the Modbury corridor and was estimated to be a Net Positive NPV project.

Then, in 1980, a new study was conducted: Public Transport in The Northeast Area of Adelaide (Department of Transport (SA), 1980). In this report, a guided busway was considered in addition to the Light Rail Transit and was focussed on these two Transit Modes. Summary of the most relevant results are presented below:

Tabl3 4-Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1980 (Department of Transport (SA), 1980).

Transit Mode	B/C Ratio (r =4%)
Light Rail	0.70
Guided-Busway	1.00

(notice that in this report, BCR was calculated with r=4% instead of 7%. Which generally produces higher NPV when the Capital Costs are relative high)

In this report, it was warned that the patronage volumes considered in previous evaluations were overestimated. It is also explained that the Guided Busway had produced better results than the Light Rail because of lower Capital Costs. In addition, it discussed that, in general, the methodology (BCA) favours minor changes (with minor expenses and immediate benefits) because long term benefits of Strategic-Long-Term options are discounted or not measured, but still such investments may be considered necessary by the community (Department of Transport (SA), 1980). It also highlighted that this methodology (BCA) is particularly valuable for ranking similar and simple schemes.

Thereafter, in 1982, the O'Bahn as we know it today (which is a guided busway) was evaluated in *Economic Evaluation of the O-Bahn* (Margaret Starrs, 1982). It maintains the same methodology with the same scope as in previous evaluations, however, the Busway layout, costs and patronage volume estimations were updated. The BCR result is listed below:

Table 5- Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1980 (Margaret Starrs, 1982).

Transit Mode	B/C Ratio (r =7%)
Guided-Busway	0.70

Nevertheless, as an annex, an additional B/C Ratio was calculated including savings in road maintenance due to diversion of buses to the Busway and diversion of car users to the O'Bahn.

After the first stage of the O'Bahn was constructed (up to Paradise Interchange in 1986) a new study was conducted in 1988: Northeast Busway Before and After Study – Final Report: Evaluation of the Busway (Department of Transport (SA), 1988). This study was not an economic evaluation. Instead, it was an operational evaluation. Patronage volumes were re-computed, this time using surveys from the existing O'Bahn, among other matters like Level Of Service, users attitude and behaviour. This was the best reference to determine patronage volumes in the past, for ex-post evaluation, and it also provided information regarding hourly and weekly patronage distribution.

Subsequently, once Stage two of the O'Bahn was finished in 1990, a couple of reports were published re-evaluating the project: An Economic Evaluation of the Northeast Busway in Adelaide (Department of Transport (SA), 1991) and The Adelaide O'Bahn – How Dood In Practice? (Chapman, 1992). At this time, the estimated BCR with the best available estimates at that times was:

Table 6-Benefit-Cost Ratios of Transit Alternatives for the Modbury Corridor evaluated in 1980 (Department of Transport (SA), 1991)

Transit Mode	B/C Ratio (r =7%)
O'Bahn	0.77

Sensitivity testing was performed and the BCR was estimated higher with the parameters tested, except only for Discount Rate r=10%.

It is worthwhile mentioning that in this report, an addition NPV and BCR was calculated with r=4% and an Evaluation period of 50 Years, which produced better BCR ratios (BCR=0.94) however, in spite of many elements of infrastructure having a lifespan of up to 80 years, it is usual to consider no more than 30 years, because further than that the time horizon is too far in the future, and it's reasonably likely to be obsoleted by technology improvements in such long periods.

Furthermore, an improvement was constructed for the O'Bahn between 2015 and 2018, the O'Bahn City Access Project. It consists of a tunnel of 660 metres, from around Princess Hwy. & Botanic Rd. (150m to the north) to approximately East Tce. & Grenfell St. (150m to the east). This project had many objectives, not only improving travel times (Dash Architects, 2015) (Infrastructure Magazine, 2017):

- Improve travel times and transport reliability, for both private and public transport, in the section under intervention.
- Develop a transport corridor that contributes to the surrounding land parks setting.
- Maintain the surrounding parks as public spaces. Maintain space for the city's events and recreation.
- Develop high quality and vibrant public spaces around East Terrace.

Nevertheless, precise information regarding traffic effects and economic evaluation was not available. Alternatively, total costs information was available and useful for Cost Benchmarking.

After reviewing past evaluation reports (generally based on forecasts), it is noticed that the NPV and BCR for this project are highly sensitive to three main parameters:

- Capital Costs
- Patronage volume
- Discount rate

However, for an ex-post analysis, all these parameters are known with better precision. In addition, non of the Evaluation Reports reviewed had presented how the benefits are distributed along the peak and non-peak hours, which would be interesting to understand when is that a transit project, such as the O'Bahn, produces most of its benefits.

2.8. Research Gap

After a careful and comprehensive literature review, some gaps were identified:

- There are no available Ex-post evaluations of the O'Bahn.
- It is not clear what options could be feasible for the future of the O'Bahn.
- Ex-ante evaluations do not present results by hourly distribution. Considering that Public Transport is very effective to reduce congestion, it would be very useful to analyse how Benefits and Costs are distributed between Peak, Inter Peak and Off Peak hours.

Furthermore, evaluations, reports and literature in general do not explain the hourly distribution of the benefits or costs. Even if this is indeed analysed for medium-detailed level analysis, results are generally not shown with its distribution. It is considered that to prepare the analysis and show the results, with its Benefits and Costs throughout Peak/Inter Peak/Off Peak hours, will provide a degree of novelty or innovation for this type of analysis.

3. Options Generation and Classification.

The original objectives for the Modbury Corridor, as described in Section 2.7, were to:

- Increase accessibility
- Reduce congestion
- Redevelop as a linear park the River Torrens Valley
- Promote the development of Tea Tree Plaza

Consequently, similar to past alternatives considered in past evaluations, only Transit Modes alternatives are generated. Considering Busway, Light Rail and Heavy Rail technologies. These options will be evaluated and compared for future scenarios. Conversely, for the Ex-post evaluation, only the O'Bahn will be analysed, and then its evaluation results will be compared with past evaluations.

3.1. Options considered

According to the evaluation methodology, a Base Case and Transit Mode options are proposed:

Table 7-Transit Options proposed

Evaluation	Alternatives	
Post-Completion (Ex-post)	0	Do nothing (Base Case)
Post-Completion (Ex-post)	1	Bus Rapid Transit (O'Bahn)
Future-Project (Ex-Ante)	2	Do nothing (Base Case)
Future-Project (Ex-Ante)	3	Bus Rapid Transit (O'Bahn)
Future-Project (Ex-Ante)	4	Bus Rapid Transit 2 (O'Bahn)
Future-Project (Ex-Ante)	5	Light Rail Rapid Transit
Future-Project (Ex-Ante)	6	Light Rail Rapid Transit 2
Future-Project (Ex-Ante)	7	Heavy Rail Rapid Transit
Future-Project (Ex-Ante)	8	Heavy Rail Rapid Transit Electric
Future-Project (Ex-Ante)	9	Heavy Rail Rapid Transit Electric 2

The Do nothing options (Alternatives 0 and 2), or Base cases, are the option of doing nothing in the Modbury corridor, with regular buses routing in normal streets, as it was before the existing O'Bahn project.

Options 1 and 3, Bus Rapid Transit, correspond to the O'Bahn as it was effectively constructed and operated, considering Articulated Buses (Bus with one articulation, two bodies).

It is important to notice that the O’Bahn limitations are not given in the guided busway nor guided busway’s stations. The Capacity of the system is limited in the CBD area, just before the beginning of the guided busway (or after the end looking from the other way around). This limitation is due to the lack of space in stops and streets in the CBD Area (Scrafton, 2019).

Then, in order to consider systems with a higher Productive Capacity (Improved Operating Speed due to reducing delays; and increased max. frequency, hence capacity), a tunnelled section in the CBD area is considered for systems with improved performance (noted with a “ 2” at the end). This type of option can be observed, for example, in the Silver Line-MBTA, Boston, Massachusetts (Massachusetts Bay Transportation Authority, 2021), where guided (similar to O’Bahn) Articulated buses (Diesel-ICE buses and Electric trolleybuses) travel on tunnels and underground stations in densely populated areas.

Option 4, Bus Rapid Transit 2, is an improved performance version of the O’Bahn, with a bigger TU capacity, improved max. frequency and higher Operating Speed, hence higher Productive Capacity. It considers Bi-Articulated Buses (Bus with two articulations, three bodies) and a tunnelled section in the CBD area.

Option 5, Light Rail Rapid Transit, is conceived to be similar to Tram services currently offered in Adelaide.

Option 6, Light Rail Rapid Transit 2, is an improved performance version of Option 5, with a bigger TU capacity, improved max. frequency and higher Operating Speed, hence higher Productive Capacity. It also considers a tunnelled section in the CBD area.

Option 7, Heavy Rail Rapid Transit, is ideated to be similar to Diesel Train services currently offered in Adelaide. It also considers a tunnelled section in the CBD area.

Option 8, Heavy Rail Rapid Transit Electric, is formulated to be similar to Electric Train services currently offered in Adelaide, which in turn uses bigger vehicles than Diesel Train cars. It considers a tunnelled section in the CBD area too.

Finally, Option 9, Heavy Rail Rapid Transit Electric 2, is an improved performance version of Option 8, with a bigger TU capacity and improved max. frequency, hence higher Productive Capacity.

A summary of Transit Mode classification by ROW, Technology and Type of Service of the options is listed below, along with their generic class (or transit category):

Table 8-Options Transit Mode classification

	Alternatives	ROW	Technology			Type of service	Generic Class
			Support	Guidance-Control	Propulsion		
0	Do nothing (Base Case)	C	Rubber tire	Steered-Visual	Diesel (ICE)	Short howl-Local-Regular+Commuter	Street transit
1	Bus Rapid Transit (O'Bahn)	A-C	Rubber tire	Guided-Visual	Diesel (ICE)	City transit-Express-Regular+Commuter	Semirapid transit
2	Do nothing (Base Case)	C	Rubber tire	Steered-Visual	Diesel (ICE)	Short howl-Local-Regular+Commuter	Street transit
3	Bus Rapid Transit (O'Bahn)	A-C	Rubber tire	Guided-Visual	Diesel (ICE)	City transit-Express-Regular+Commuter	Semirapid transit
4	Bus Rapid Transit 2 (O'Bahn)	A	Rubber tire	Guided-Visual	Diesel (ICE)	City transit-Express-Regular+Commuter	Semirapid transit
5	Light Rail Rapid Transit	A-C	Steel wheel	Guided-Vis.Sig.	Electric (DC)	City transit-Express-Regular+Commuter	Semirapid transit
6	Light Rail Rapid Transit 2	A	Steel wheel	Guided-Vis.Sig.	Electric (DC)	City transit-Express-Regular+Commuter	Semirapid transit
7	Heavy Rail Rapid Transit	A	Steel wheel	Guided-Vis.Sig.	Diesel-Electric (DEL)	City transit-Express-Regular+Commuter	Rapid transit
8	Heavy Rail Rapid Transit Electric	A	Steel wheel	Guided-Vis.Sig.	Electric (DC)	City transit-Express-Regular+Commuter	Rapid transit
9	Heavy Rail Rapid Transit Electric 2	A	Steel wheel	Guided-Vis.Sig.	Electric (DC)	City transit-Express-Regular+Commuter	Rapid transit

In addition, a summary with characteristics of the Transit options ways are listed below:

Table 9- Transit Options Ways characteristics

	Alternatives	route/ line	Lane Width [m]	Lanes [u]	Station spacing [m]	Reliability	Safety	Comfort	Noise Levels	Life-span [yr]
0	Do nothing (Base Case)	Roads	3.7	2	350	Low	Med	Low	High	30
1	Bus Rapid Transit (O'Bahn)	Exclusive lane	3	2	3000-6000	High	Very-High	High	Med	70
2	Do nothing (Base Case)	Roads	3.7	2	350	Low	Med	Low	High	30
3	Bus Rapid Transit (O'Bahn)	Exclusive lane	3	2	3000-6000	High	Very-High	High	Med	70
4	Bus Rapid Transit 2 (O'Bahn)	Exclusive lane	3	2	3000-6000	Very-High	Very-High	High	Med	70
5	Light Rail Rapid Transit	Exclusive Railway	3.5	2	3000-6000	High	Very-High	Very-High	Low	70
6	Light Rail Rapid Transit 2	Exclusive Railway	3.5	2	3000-6000	Very-High	Very-High	Very-High	Low	70
7	Heavy Rail Rapid Transit	Exclusive Railway	4.0	2	3000-6000	Very-High	Very-High	High	Med	70
8	Heavy Rail Rapid Transit Electric	Exclusive Railway	4.0	2	3000-6000	Very-High	Very-High	Very-High	Low	70
9	Heavy Rail Rapid Transit Electric 2	Exclusive Railway	4.0	2	3000-6000	Very-High	Very-High	Very-High	Low	70

Reliability refers to the level of compliance with the service schedule. Generally, reliability increases with higher ROW. Moreover, improved performance options are expected to offer better reliability.

Safety indicates the protection against and reduction of traffic accidents. In the same way, higher ROW offers higher safety levels.

Comfort, in general terms, is perceived higher with smoother driving (affected by ROW), lower vibrations (affected by support and guidance), lower noise levels, and other characteristics. Generally, Rail modes are considered more comfortable than Bus modes.

Noise Level is highly influenced by the propulsion technology and driving regimes (which is affected by ROW)

The lifespan of the way is based on ATAP Guidelines (Transport and Infrastructure Council, 2018), assuming proper maintenance and replacement of sub-elements with less durability.

3.2. Options performance

The Transit Mode options performance indicators were adopted based on practical values observed in Adelaide Transit System, considering typical vehicle's technical specifications and service schedule at peak hours (Adelaide Metro, 2020); (DPTI, 2018); (Veitch Lister Consulting, 2019); (Metro Report International, 2019); (ACT Bus, 2014); (ACT Bus, 2012). Furthermore, the improved performance options consider a reasonable improvement in performance based on other systems with higher performance (Transport NSW, 2020) (Public Transport Victoria, 2020). The following table shows the performance indicators of the options considered, which were discussed and revised by Prof. Dr. Derek Scrafton (University of South Australia), who is an expert in transport and transit planning:

Table 10-Transit Mode options performance indicators

Evaluation		Alternatives	TU Vehicle	seat cap. [sps/TU]	crush cap. (Cv) [sps/TU]	Operating speed (Vo) [km/h]	frequency/ lane (fm) [TU/h]	Transit Capacity/ lane [sps/h]	Capacity/ lane (Pc) [sps-km/h-h]	Way Density (D2)	Lifespan [yr]
Post-Completion	0	Do nothing (Base Case)	Bus	48	65	26	40	2600	67600	270	12
Post-Completion	1	Bus Rapid Transit (O'Bahn)	A.Bus	65	88	40	40	3520	140800	293	12
Future-Project	2	Do nothing (Base Case)	Bus	48	65	26	40	2600	67600	270	12
Future-Project	3	Bus Rapid Transit (O'Bahn)	A.Bus	65	88	40	40	3520	140800	293	12
Future-Project	4	Bus Rapid Transit 2 (O'Bahn)	Bi-A.Bus	82	110	50	50	5500	275000	367	12
Future-Project	5	Light Rail Rapid Transit	Car train	60	140	40	20	2800	112000	200	30
Future-Project	6	Light Rail Rapid Transit 2	Car train	150	350	50	25	8750	437500	500	30
Future-Project	7	Heavy Rail Rapid Transit	Car train	205	336	50	12	4032	201600	202	30
Future-Project	8	Heavy Rail Rapid Transit Electric	Car train	240	540	50	15	8100	405000	405	30
Future-Project	9	Heavy Rail Rapid Transit Electric 2	Car train	480	1080	50	20	21600	1080000	1080	30

3.3. Options Capital Costs

As mentioned in Section 2.6, Capital Costs were estimated using a Cost Benchmarking process (Royal Institution of Chartered Surveyors (RICS), 2011). This process requires a Cost model for project analysis and comparison, which is summarized below:

Tabla 11-Transit Mode Options – Capital Costs model

Alternatives		Capital Costs (CC) Scope
0	Do nothing (Base Case)	No CC required
1	Bus Rapid Transit (O'Bahn)	12 km of Guided-Busway track & Stations (3)
2	Do nothing (Base Case)	No CC required
3	Bus Rapid Transit (O'Bahn)	12 km of Guided-Busway track & Stations (3)
4	Bus Rapid Transit 2 (O'Bahn)	12 km of Guided-Busway track & Stations (3) + 2 km Tunnelled Section + 1 Underground Station.
5	Light Rail Rapid Transit	12 km of Light Rail track (electrified) + 3 Rail Stations
6	Light Rail Rapid Transit 2	12 km of Light Rail track (electrified) + 3 Rail Stations + 2 km Tunnelled Section + 1 Underground Station.
7	Heavy Rail Rapid Transit	12 km of Heavy Rail track + 3 Rail Stations + 2 km Tunnelled Section + 1 Underground Station.
8	Heavy Rail Rapid Transit Electric	12 km of Heavy Rail track (electrified) + 3 Rail Stations + 2 km Tunnelled Section + 1 Underground Station.
9	Heavy Rail Rapid Transit Electric 2	12 km of Heavy Rail track (electrified) + 3 Rail Stations + 2 km Tunnelled Section + 1 Underground Station.

Notes:

Transit Units procurement costs, maintenance and replacement are included in Operational Costs. The Way construction assumes 2 lanes, one in each direction.

It is important to notice that the Capital Costs of Track construction (12km) includes all the necessary elements related to the linear construction, such as Earthworks, Landscaping (it was considered in past evaluations as well), Structures, Track, Bridges, overpasses/underpasses, etc.

Conversely, costs related to the 660m tunnel near East Terrace are not included in the costs, seeing that there are other options from the transport point of view (e.g. extra pair of at-grade exclusive guided-bus lanes. without tunnel), yet this project had many urban development considerations (refer to O-Bahn city Acces project mentioned in Section 2.7). Therefore, it is considered that these costs shall not be considered. In regards to the benefits, refer to Section 4.3.

As a result, the Benchmark Cost models are defined below:

- Way Construction Costs for Guided-Busway, including stations, expressed in [A$M/lane-km] (Millions of Australian Dollars per one lane-one kilometre)
- Way Construction Costs for Light Rail, excluding stations, expressed in [A$M/lane-km]
- Way Construction Costs for Heavy Rail, excluding stations, expressed in [A$M/lane-km]
- Way Construction Costs for Electrified Heavy Rail, excluding stations, expressed in [A$M/lane-km]
- Station Construction for Rail Modes, expressed in [A$M/station]
- Underground Station Construction for all Transit Modes, expressed in [A$M/station]
- Tunnelled section Construction Costs, excluding way construction costs, excluding underground station in the CBD, for all Transit Modes, expressed in [A$M/lane-km]

Subsequently, the Cost Benchmarking process requires collecting cost data. For the Guided-Busway, the effective cost data from the O'Bahn was considered (Department of Transport (SA), 1991). In addition, cost data of Light Rail and Heavy Rail transit projects were found among the Project Business Case Evaluation Summary of major transport projects in Australia (Infrastructure Australia, 2020). Projects considered were:

- O'Bahn Guided-Busway – Adelaide SA (Department of Transport (SA), 1991) (Guided Busway CC, including stations)
- O'Bahn City Access – Adelaide SA (Department for Infrastructure and Transport, 2018) (Tunnelled section CC in urban areas)
- Gold Coast Light Rail: Stage 2 – Gold Coast QLD (Australian Government, 2016) (Electrified Light Rail)
- Gold Coast Light Rail: Stage 3A – Gold Coast QLD (Infrastructure Australia, 2019)
- METRONET: Thornlie Cockburn – Perth WA (Infrastructure Australia, 2018) (Heavy Rail)
- METRONET: Yanchep Rail Extension – Perth WA (Infrastructure Australia, 2018) (Heavy Rail)
- Byford Rail Extension – Perth WA (Infrastructure Australia, 2020) (Electric Heavy Rail)
- Frankston to Baxter Rail Upgrade – Mornington Peninsula VIC (Australian Government, 2019) (Electric Heavy Rail)
- Flinders Link – Adelaide SA (Australian Government, 2019) (Electric Heavy Rail)
- Gawler Rail Line Electrification – Adelaide SA (Australian Government, 2018) (Electrification of a Heavy Rail Line)
- ATAP Guidelines – Railway track formation (M1-Table 34) (Transport and Infrastructure Council, 2018)
- ATAP Guidelines – Railway track formation Tunnelled (M1-Table 34) (Transport and Infrastructure Council, 2018)
- ATAP Guidelines – Light Rail (M1-Table 34) (Transport and Infrastructure Council, 2018)

- ATAP Guidelines – Dedicated Bus Lanes (M1-Table 34) (Transport and Infrastructure Council, 2018)
- ATAP Guidelines – Railway Station Surface (M1-Table 34) (Transport and Infrastructure Council, 2018)
- ATAP Guidelines – Interchanges (M1-Table 34) (Transport and Infrastructure Council, 2018)

A summary of the Cost Data analysed is listed in Appendix B.

After collecting and analysing data, the Cost Benchmarking process requires adopting cost indexes according to the model and cost data analysed. The cost data were analysed and then discussed and revised with Prof. Dr. Derek Scrafton (University of South Australia). Benchmark Cost Indexes were selected based on the ATAP Guidelines Benchmark Costs as the main reference. It was revised the relative difference between projects Busways-Light Rail-Heavy Rail, using the Real O'Bahn Capital Costs as a reference, and finally comparing Total Capital Costs of different Options with similar real project's value.

The Benchmark Cost Indexes adopted are listed below (prices in Dec-2020):

- Way Construction Costs for Guided-Busway: 13 [A$M/lane-km]
- Way Construction Costs for Light Rail: 40 [A$M/lane-km]
- Way Construction Costs for Heavy Rail: 44 [A$M/lane-km]
- Way Construction Costs for Electrified Heavy Rail: 50 [A$M/lane-km]
- Station Construction for Rail Modes: 15 [A$M/station]
- Underground Station: 60 [A$M/station]
- Tunnelled section: 60 [A$M/lane-km]

Finally, a summary of Construction Costs is listed in the table below:

Tabla 12-Transit Mode Options - Capital Costs

	Alternatives	Way Construction [A$M/lane-km]	Way Cost [A$M]	CBD Tunnel (2km) & Station Cost [A$M]	Station Costs (x3) [A$M]	Total Cap. Cost [A$M]
0	Do nothing (Base Case)	0.0	0			0
1	Bus Rapid Transit (O'Bahn)	13.0	312			312
2	Do nothing (Base Case)	0.0	0			0
3	Bus Rapid Transit (O'Bahn)	13.0	312			312
4	Bus Rapid Transit 2 (O'Bahn)	13.0	312	300		612
5	Light Rail Rapid Transit	40	960		45	1005
6	Light Rail Rapid Transit 2	40	960	300	45	1305
7	Heavy Rail Rapid Transit	44.0	1056	300	45	1401
8	Heavy Rail Rapid Transit Electric	50	1200	300	45	1545
9	Heavy Rail Rapid Transit Electric 2	50	1200	300	45	1545

3.4. Options comparison

A set of graphs were plotted to compare Transit Mode options with the parameters defined throughout chapter 3, which is specific for the Modbury Corridor, Adelaide.

It is worth mentioning that “Investment Cost/pair of lanes” includes all the capital costs analysed in Section 3.3 (for two lanes, one in each direction). Conversely, performance parameters correspond to only one lane. It is listed this way considering that, at a peak hour (AM or PM), only one direction (i.e. one lane) has the peak demand.

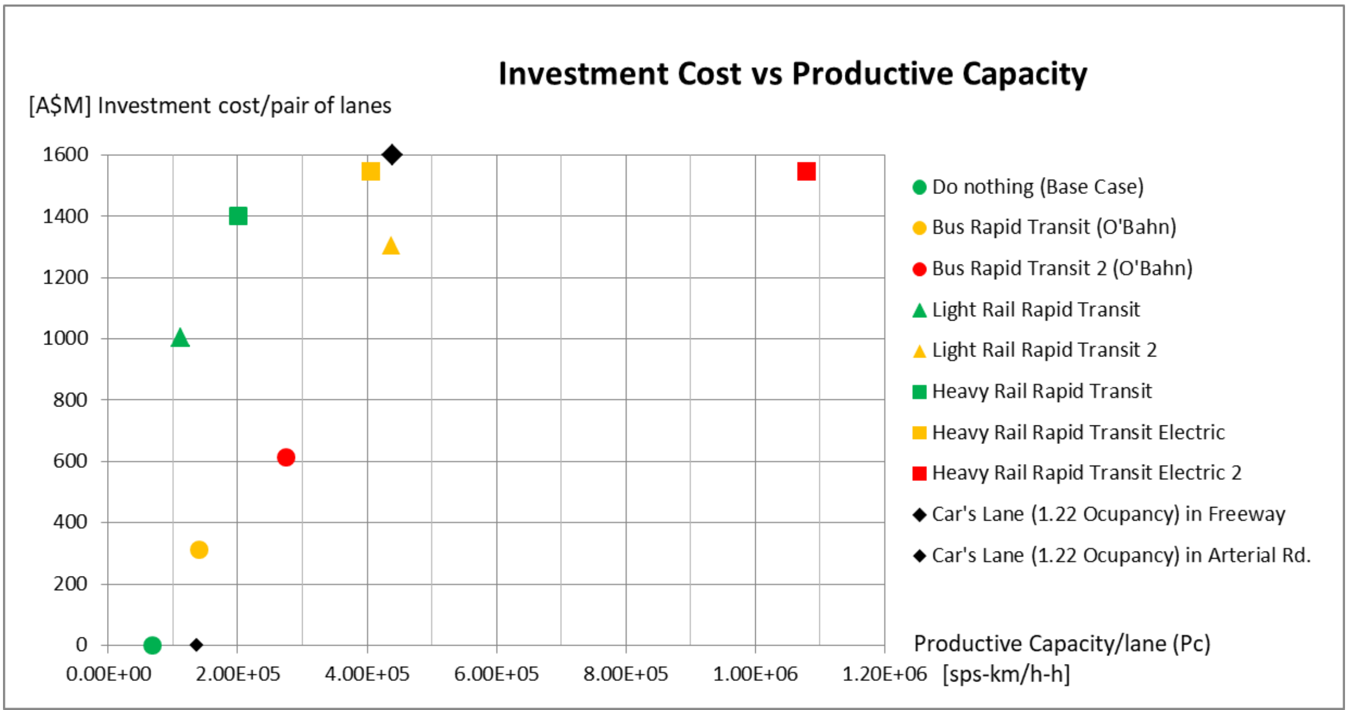

Figure 10-Transit Mode options – Investment Cost vs Productive Capacity

Similar to Section 2.3 – Figure 6, it can be observed that Heavy Rail can offer much higher productive capacity, but investment costs are the highest as well. Even though the O’Bahn options are competitive with Light Rail options, Light Rail options require higher Capital Costs and can potentially offer higher Productive Capacity with the improved performance version. In addition, Car roads options are showed for reference. For the Freeway, the cost is considering 6 lanes (3 lanes in each direction) and performance is shown for 3 lanes in the peak direction. Car Options (such as a freeway) are very competitive and are deemed to offer, in general, better NPV and BCR. However, investment costs are high and, in this case, do not align with the project’s objectives (refer to Section 2.7).

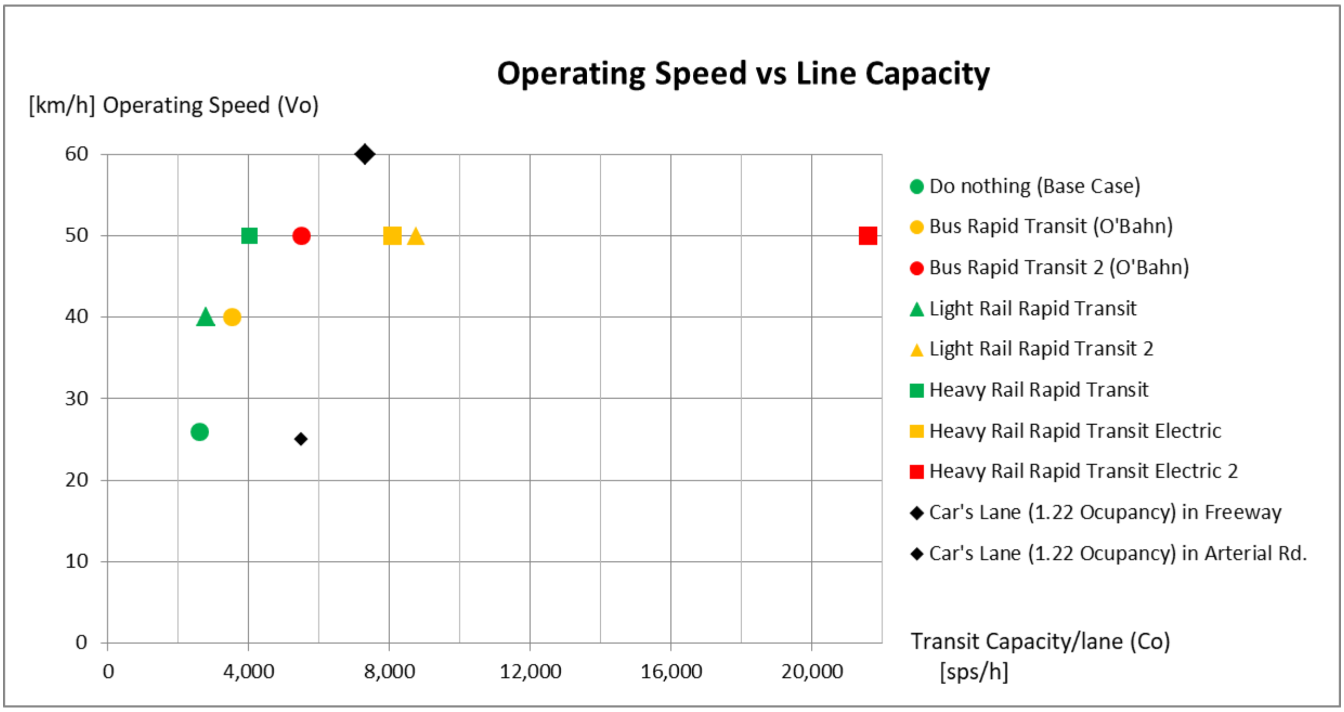

Figure 11-Transit Mode options – Operating Speed vs Line Capacity

In this figure, both components of the Productive Capacity are plotted. It can be seen that improved performance options (which involves the construction of a tunnelled section in the CBD area) offer higher Operating Speed (due to reduction of delays in the CBD) and higher Transit Capacity (considering bigger Transit Units and improved frequency).

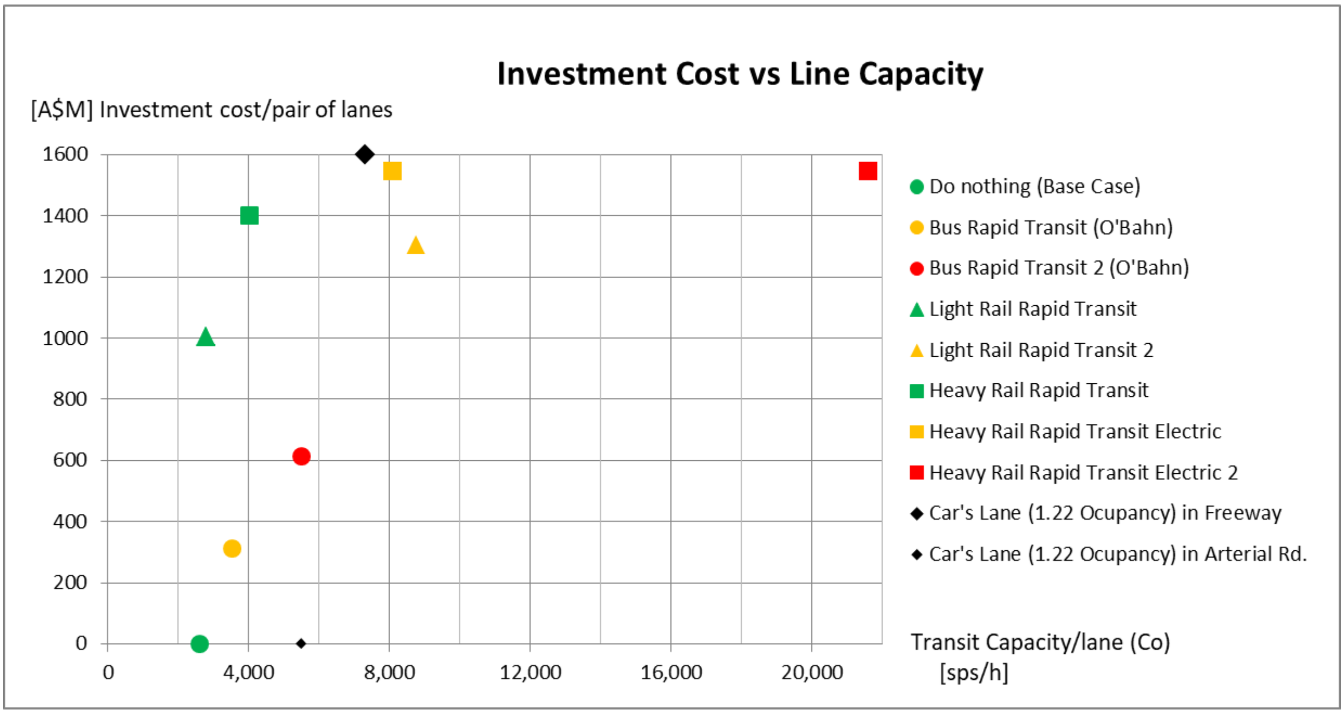

Figure 12-Transit Mode options – Investment Cost vs Line Capacity

This graph has a similar plotting as to Figure 10. Nevertheless, Capacity is plotted (which does not take into account the operating speed of the system). With this type of graph, is easier to compare demand with Line Capacity.

The following graphs plot the Way Density (D2), which is measured in spaces per hectare, compared with Way Capacity. It can be noticed that, for transit options, higher Capacity can be achieved along with higher Way Density. In contrast, Car options work with much lower density, requiring more space to achieve higher capacity.

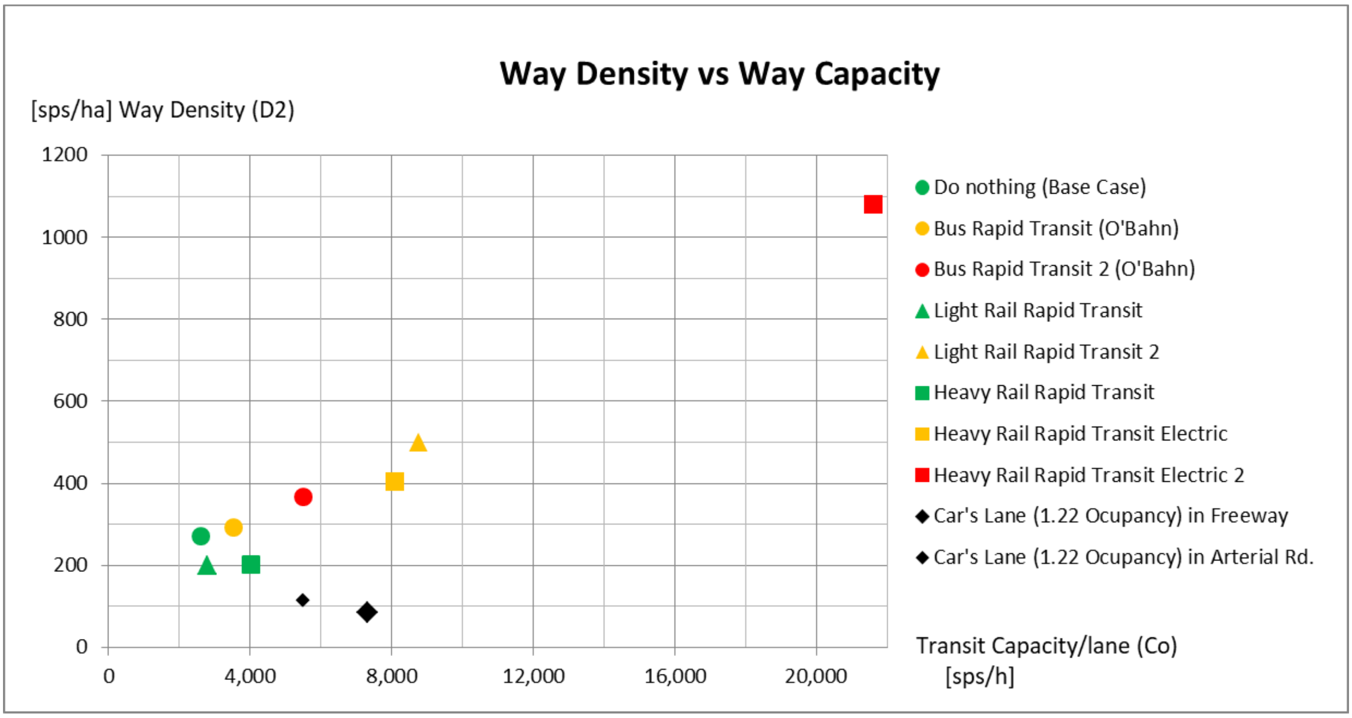

Figure 13-Transit Mode options – Investment Cost vs Way Capacity

Finally, Investment Cost vs Way Density has a similar plot as to figure 10. In general, systems that can offer higher density will require higher investment costs.

Except for Car options, where, in general, density is not highly influenced by the technology of vehicle nor way characteristics. Instead, it is highly affected by the Occupancy rate (average amount of people per car).

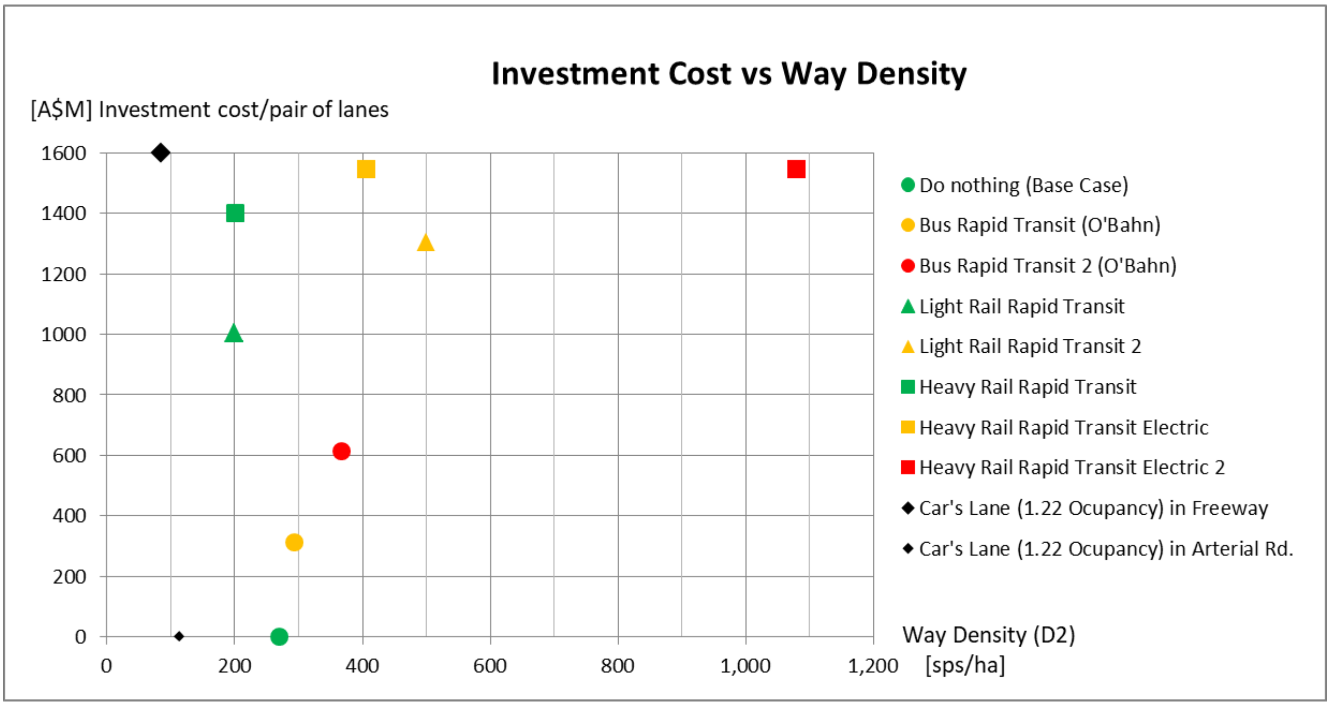

Figure 14-Transit Mode options – Investment Cost vs Way Density

4. Benefits and Costs identification.

For the Benefit-Cost Analysis, financial costs and benefits are accounted in all options. Such financial cash flow is comprised of Capital Costs, Operational Costs and Fare revenue.

In addition, economic, social and environmental benefits, which are calculated using economic values (or shadow prices), are accounted only as of the difference with the Base Case. These benefits are generated due to costs reduction or costs saving, such as Travel Time savings, Car operation savings, Environmental Costs reduction, etc.

4.1. Costs considered

- Capital Costs (CC) (mostly comprised of tracks and stations construction).
- Transit Operation Costs (including all expenses for the operation of the transit lines, maintenance and vehicle replacement of vehicles).

4.2. Benefits considered

- Fare revenue
- Transit Travel Times savings (it considers the In-Vehicle Time (IVT) and time penalties related to reliability, schedule, interchanges, etc.).
- Car Travel Times savings (it considers the travel time savings of the remaining car users due to the diversion of commuters to the transit system).
- Car Operation savings (it considers the car costs avoided by diverted users from car to transit, including car ownership costs and accident costs).
- Transit Environmental costs reduction (considers the change in environmental costs caused by different transit options).
- Car Environmental costs reduction (it accounts for the car environmental costs avoided by diverted users from car to transit).
- Residual Value (the value of the infrastructure at the end of the evaluation period.
- Option and Non-Use value (it accounts for the willingness-to-pay for the existence and continuation of service, whether is directly used or not directly used, as long as it is within the area of influence of the service/project (Transport and Infrastructure Council, 2018))

4.3. Impacts not considered

The following potential impacts not considered in the analysis are overlooked due to having low relevance in the BCA (Victoria Transport Policy Institute, 2020), or because they are out of the scope of the analysis:

- Parking costs/benefits (in spite of being an important component of the transport system, it is considered out of scope because the options do not produce changes in parking systems compared to the existing O'Bahn constructed. Even though parking matters are very relevant to Modal choices, Mode choice analysis is out of scope in this thesis).
- Project construction traffic delays (considered of low relevance in BCA).
- Strategic Land use impacts, and Land value (considered of low relevance and out of scope in the BCA. In addition, there would be a risk of double-counting benefits with Option and Non-Use value).
- Transportation diversity and accessibility (considered of low relevance in BCA, assuming accessibility is already provided).
- Impacts on physical activity and public health (considered of low relevance in BCA).
- Impacts on non-motorized travels (considered of low relevance in BCA).
- Tax effects (considered of low relevance in BCA and out of scope).
- Equity and public goods are not accounted (considered of low relevance and out of scope in the BCA. In addition, there would be a risk of double-counting benefits with Option and Non-Use value).
- Economy and jobs impacts (considered of low relevance in BCA and out of scope).

Finally, regarding the impacts produced by the O-Bahn City Access Project (660m tunnelled section around East Terrace constructed in 2018):

- Costs were not considered seeing that there are other options from the transport point of view and this project had many urban development considerations.
- Since benefits, savings or costs reductions are measured against the base case, and data for BCA is based mostly on 2020-2021 data, any benefit produced by this project would be cancelled. This consideration may lead to errors in benefit calculations. However, since the section is relatively short (around 8% of the O'Bahn), it is assumed that the errors induced by this consideration are of low relevance.

5. Transport Model.

The BCA of Transit Options is meant to aid the selection of the best alternative at a strategic level before progressing to a specific detailed design. Therefore, a transport Macro Model of low resolution (a model involving the Four-Step Process, designed for the aggregate analysis of transport projects and their impacts) is suitable for solving a wide engineering issue and narrowing options to one specific project (Nicholas Holyoak, 2005)

The following parameters are sought to be obtained from the Macro Model:

- Transit former users (daily amount of people using the public transport, and would still use it without the Transit Project).
- Transit diverted users (daily amount of new people using the Transit Project, that would not be using public transport otherwise).
- Car Volume in roads affected by Transit Project.
- Travel Time savings for Transit users.
- Travel Time savings for Car users due to diversion of commuters to Public Transport.

5.1. Data collection and Scope

The following databases were used to develop the Transport Model:

- Adelaide Maps from Google Maps (Google , 2021).
- Bus routes and timetable from Adelaide Metro (Adelaide Metro, 2021) (also refer to Appendix A).
- O'Bahn Daily Boardings and surveys (Government of South Australia, 2017, as cited in (Scrafton, 2019)), (Department of Transport (SA), 1988) and (Department of Transport (SA), 1991).
- Adelaide's Roads AADT (Department for Infrastructure and Transport, 2021).
- SCATS traffic counts data for relevant intersections (2017, provided by professor Branko Stazic).
- Bluetooth Detection Sites (same as SCATS sites) (South Australian Government Data Directory, 2021).
- Bluetooth Travel Time measurements (South Australian Government Data Directort, 2017).

- Carpooling and occupancy rates surveys (Charting Transport, 2017) and (South Australian Government Data directory, 2019).
- Traffic growth records and predictions in Adelaide (Dr David Gargett, 2002).
- Population records and predictions in Adelaide (Australian Bureau of Statistics, 2021)

In addition, two types of surveys were performed for this thesis to validate the Model:

- Car Travel Time survey (refer to Appendix C) based on Traffic Studies and Analysis (Department of Transport and Main Roads QLD, 2013)
- O'Bahn observations (refer to Appendix D)

Periods considered for modelling:

- Ex-Post analysis: 1990-2020
- Ex-Ante analysis: 2020-2050

For Ex-Post analysis, the available records are used to estimate the model parameters. On the other hand, for Ex-Ante analysis, three scenarios are proposed:

- T. Scenario 0: Transport demand for Ex-Post analysis is based on available records.
- T. Scenario 1: Transport growth (for Ex-Ante) is based on population projections for Adelaide (avg. rate 0.74%). Mode Choice (or Modal split) assumed to remain the same. This is considered the best available estimation.
- T. Scenario 2: Transport growth rate increased. Adopting the average growth rate of the North-East suburbs of the last 20 years (rate adopted 1.2%). Mode Choice (or Modal split) assumed to remain the same. This is analysed for sensitivity, and considered a realistic scenario.
- T. Scenario 3: Transport growth rate and Transit slip increased. 2% growth rate adopted and 10% increase in transit patronage, being new diverted users. This is analysed for sensitivity. This scenario aims to evaluate results with a high increment in the demand.

5.2. Transport network

The O'Bahn, in the Modbury Corridor, mainly serves travellers to and from the CBD Area. Some people would interchange buses in the stations to travel locally around it. In addition, parking facilities are offered in the stations for customers to transfer to public transport as part of their journey (Adelaide Metro, 2021).

On the other hand, in order to simplify the network (which is acceptable for a Macro Model low-resolution), Travel Times required to travel to and from Transit Stations or Road Network Nodes is neglected. It is assumed that a transit project in the Modbury Corridor would not produce considerable changes in those parts of a trip.

The following map and tables show the main elements of the network:

- Transit Route (Modbury Corridor)
  - 4 nodes (4 stations)
  - 3 links
- Road affected by Transit project: North East Road (NER)
  - 5 nodes (intersections listed in the map)
  - Id (a number) of intersections with available Scats and Bluetooth data
  - 4 links
- Road affected by Transit project: Lower North East Road (LNER)
  - 5 nodes (intersections listed in the map)
  - Id (a number) of intersections with available Scats and Bluetooth data
  - 4 links

Note: These two roads, NER and LNER, are the main options to go to (and from) the CBD Area, by car, from (and to) locations around the Modbury Corridor.

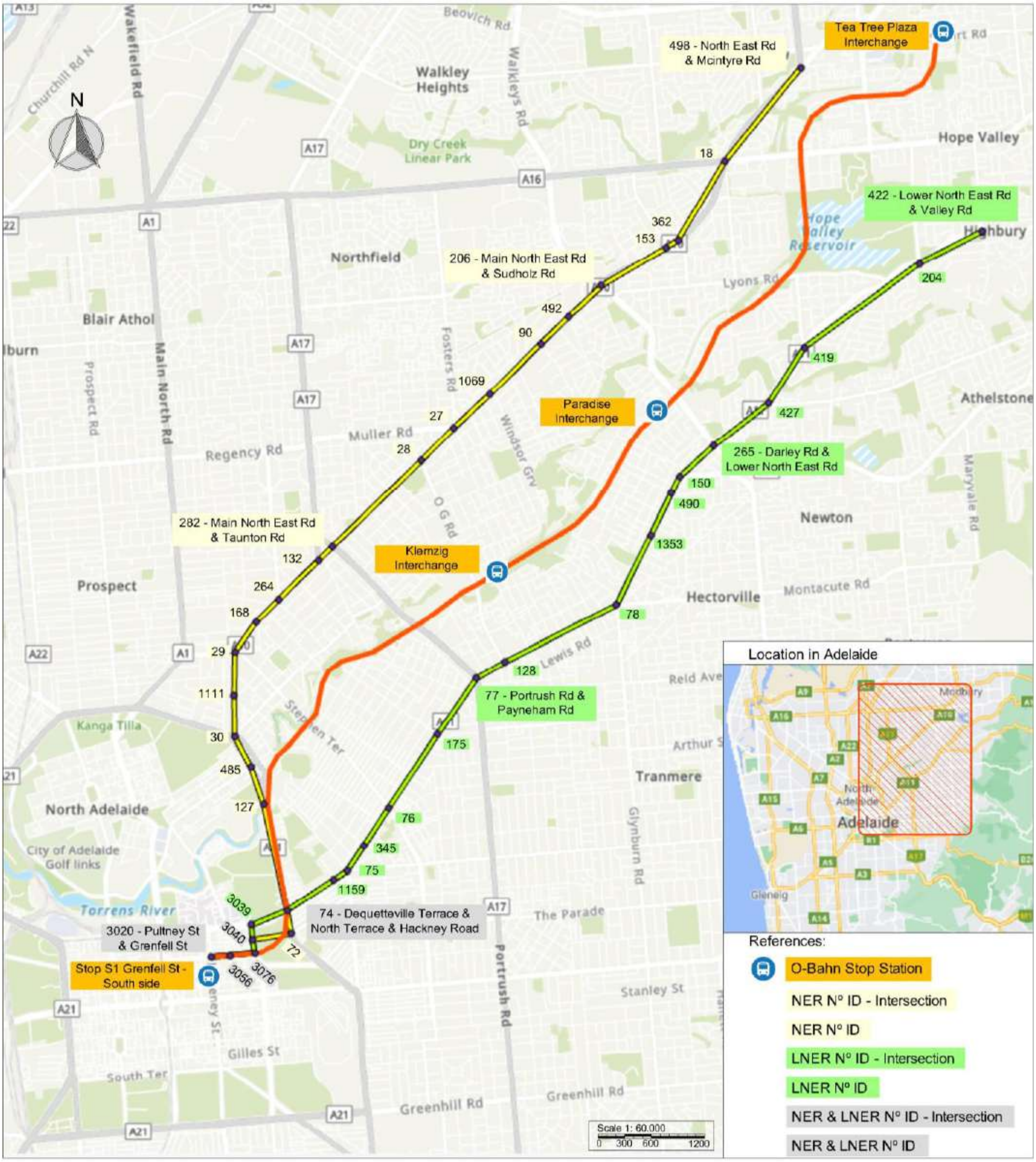

Figure 15-Network of Thesis Transport Model

Table 13-Nodes and Links of Transit Route

Id	Name	CH [m]	Link length [m]
CBD	Stop S1 Grenfell St	0	
Klemzig	Klemzig Interchange	5000	5000
Paradise	Paradise Interchange	8000	3000
Tea Tree Plaza	Tea Tree Plaza Interchange	13000	5000

Table 14- Nodes and Links of North East Road (NER)

Id	Name	CH [m]	Link length [m]
3020	PULTNEY ST - GRENFELL ST	0	
3056	GRENFELL STREET - FROME STREET	220	220
3076	GRENFELL STREET - EAST TERRACE	450	230
3040	EAST TERRACE - RUNDLE ROAD	650	200
72	DEQUETTEVILLE TERRACE - RUNDLE STREET	1100	450
74	DEQUETTEVILLE TERRACE -NORTH TERRACE -HACKNEY ROAD	1300	200
127	PARK TERRACE - BUNDEYS ROAD RN	2500	1200
485	NORTH CITY RING ROUTE MELBOURNE ST	3100	600
30	NORTHCOTE TERRACE-ROBE TERRACE-MANN TERRACERN	3500	400
1111	NORTHCOTE TERRACE N OF EDWIN TERRACE MEDINDIE	3900	400
29	NORTH EAST ROAD -NORTHCOTE TERRACE-STEPHEN TERRACE	4400	500
168	NORTH EAST ROAD SMITH ST	4800	400
264	NORTH EAST ROAD GALWAY AV	5200	400
132	NORTH EAST ROAD HAMPSTEAD ROAD	5800	600
282	MAIN NORTH EAST ROAD - TAUNTON ROAD	6000	200
28	NORTH EAST ROAD POOLE AV OG ROAD	7400	1400
27	NORTH EAST ROAD MULLER ROAD	7900	500
1069	NORTH EAST ROAD SW OF WINDSOR GROVE WINDSOR GARDENS	8500	600
90	NORTH EAST ROAD INNES ROAD	9300	800
492	NORTH EAST ROAD PITMAN ROAD	9700	400
206	MAIN NORTH EAST ROAD - SUDHOLZ ROAD	10200	500
153	NORTH EAST ROAD WANDANA AV	11000	800
362	NORTH EAST ROAD TARTON ROAD	11200	200
18	GRAND JUNCTION ROAD - NORTH EAST ROAD	12300	1100
498	NORTH EAST ROAD MCINTYRE ROAD	13600	1300

Table 15- Nodes and Links of Lower North East Road (LNER)

Id	Name	CH [m]	Link length [m]
3020	PULTNEY ST - GRENFELL ST	0	
3056	GRENFELL STREET - FROME STREET	220	220
3076	GRENFELL STREET - EAST TERRACE	450	230
3040	EAST TERRACE - RUNDLE ROAD	650	200
3039	NORTH TERRACE - EAST TERRACE	800	150
74	DEQUETTEVILLE TERRACE -NORTH TERRACE -HACKNEY ROAD	1200	400
1159	NORTH TERRACE SW OF TRINITY STREET COLLEGE PARK	1900	700
75	PAYNEHAM ROAD -MAGILL ROAD -FULLARTON ROAD	2000	100
345	PAYNEHAM ROAD - HARROW ROAD RN	2400	400
76	PAYNEHAM ROAD -NELSON ST -STEPHEN TERRACE	2900	500
175	PAYNEHAM ROAD - LAMBERT ROAD RN	3900	1000
77	PORTRUSH ROAD - PAYNEHAM ROAD	4600	700
128	PAYNEHAM ROAD - OG ROAD	5000	400
78	LOWER NTH EAST ROAD -MONTACUTE ROAD -GLYNBURN ROAD	6400	1400
1353	LOWER NORTH EAST ROAD BETWEEN LENNOX ST & HEADING AVE CAMPBELLTOWN	7300	900
490	LOWER NORTH EAST ROAD -ANN STREET	7800	500
150	LOWER NORTH EAST ROAD - GORGE ROAD	8000	200
265	DARLEY ROAD - LOWER NORTH EAST ROAD	8500	500
427	LOWER NORTH EAST ROAD - GEORGE STREET	9300	800
419	LOWER NORTH EAST ROAD - BALMORAL ROAD	10100	800
204	LOWER NORTH EAST ROAD -AWOONGA ROAD	11700	1600
422	LOWER NORTH EAST ROAD-VALLEY ROAD	12500	800

The Lengths of Links in the network model are now referred as:

[L transit]i (matrix of links length for the Transit Project)

Table 16-[L transit]

Links - Transit [m]		
CBD - Klemzig	Klemzig - Paradise	Paradise -Tea Tree Plaza
5000	3000	5000

[L cars]i (matrix of links length for NER and LNER)

Table 17-[L cars]

Links - North East Road [m]				Links - Lower North East Road [m]			
3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422
1300	4700	4200	3400	1200	3400	3900	4000

5.3. Trip Generation

Trip generation is directly based on current demand. For transit past demand, a simple linear interpolation was made with past Transit demand from Survey Data.

- O'Bahn demand in 1990: 22.800 passengers/day (Department of Transport (SA), 1991)
- O'Bahn demand in 2018: 31.000 passengers/day (Government of South Australia, 2017, as cited in (Scrafton, 2019))

The Daily Transit Patronage in the year t is now referred as: dPt (a scalar)

For Volumes in NER and LNER, the AADT (Department for Infrastructure and Transport, 2021) averaged between nodes was adopted for every link:

Table 18-[V cars]2018 (Average AADT for Road network links in 2018)

	->Links	North East Road - AADT [veh/day]				Lower North East Road - AADT [veh/day]			
Year	Growth Coef.	3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422
2018	1.000	15200	42517	43120	44875	15200	31400	39940	29240

The Traffic Volume in links in the year t is now referred as: **[V cars]t** (a matrix)

For Past Volumes in NER and LNER (T.Scenario 0), the Growth coefficient is based on "vehicle kilometres travelled by type of vehicle for Adelaide, 1990-2020" (Dr David Gargett, 2002).

For future Forecasts, T.Scenario 1 growth is based on Future Population forecasts (Average 0.74% annual growth rate); T.Scenario 2, an annual growth rate of 1.2% was adopted; T.Scenario 3, an annual growth rate of 2.0% was adopted (refer to Section 5.1).

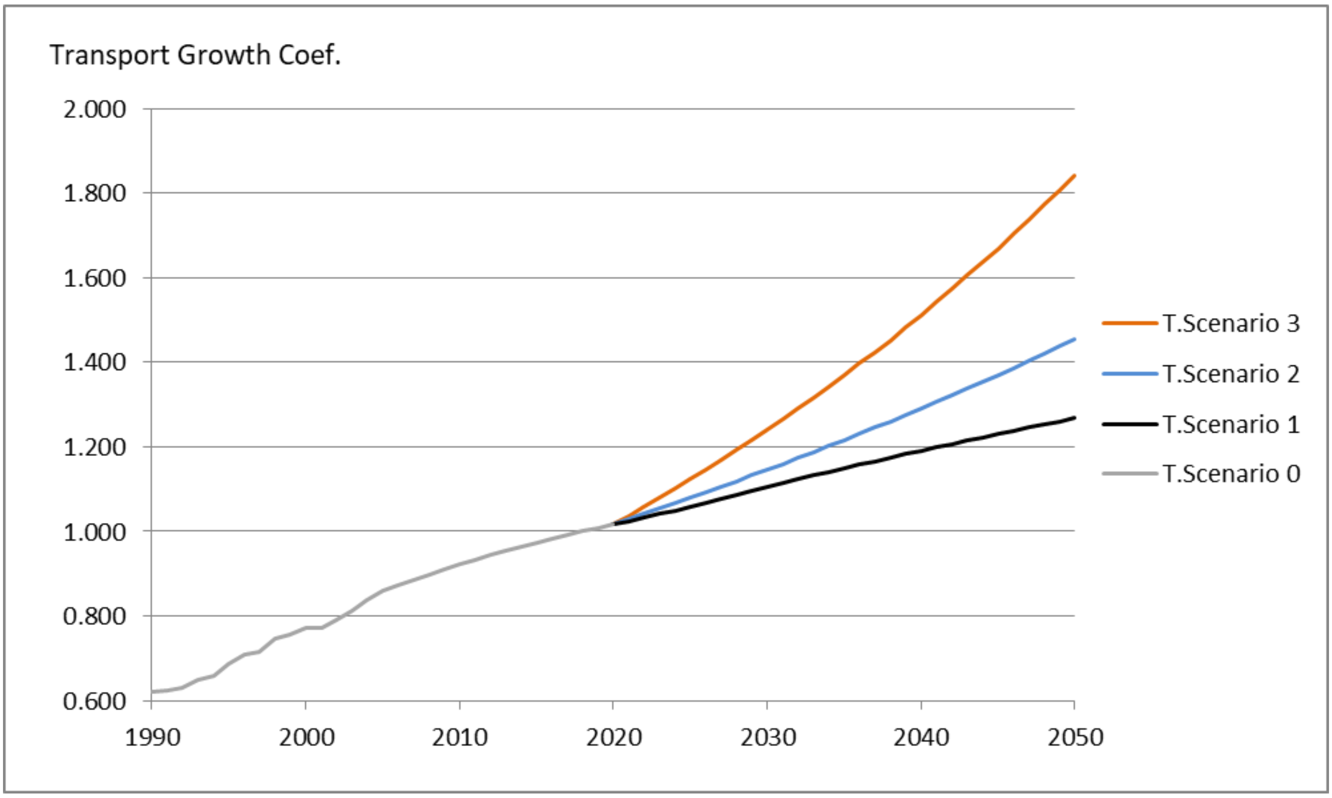

Figure 16-Transport Growth coefficients

5.4. Trip Distribution, Mode Choice and Trip Assignment

Owing to the network being modelled with fixed routes (Transit Route, NER and LNER), and Mode Choices assumed fixed as well (except for T. Scenario 3 with an arbitrary Mode shift), the Trip Distribution, Mode Choice and Assignment are simplified to:

- Trips Volumes in NER and LNER as adopted in the previous section
- Transit Users as adopted in the previous section (dPt) with the following distribution:
    - 55% to/from Tea Tree Plaza (Based on observations. Refer to Appendix D)
    - 35% to/from Paradise
    - 10% to/from Klemzig
- As a result, the following matrix presents the trip assignment in the transit line, now referred as **[V transit]**:

Table 19- [V transit]

Links Patronage - Transit		
CBD - Klemzig (p1)	Klemzig - Paradise (p2)	Paradise -Tea Tree Plaza (p3)
1.00	0.90	0.55

Nevertheless, similar simplifications were adopted for the Base Case and also for T.Scenario 3, based on the following considerations:

- O'Bahn Patronage in 1989: 20.800 passengers/day (Department of Transport (SA), 1991)
- O'Bahn Patronage in 1990: 22.800 passengers/day (Department of Transport (SA), 1991) (based on before and after O'Bahn Patronage Surveys)

- > Transit Users: 90% Former Users + 10% Diverted Users (DU) (T.Scenario 1 and 2)
- > Transit Users (T.Scenario 3): 90% Former Users + 10% Diverted Users (DU) + 10% New Diverted Users (NDU)
  - Diverted Users: **DUt** = 10%dPt
  - New Diverted Users: **NDUt** = {0 for T.Scenario 1 and 2; 10%dPt for T.Scenario 3}

Moreover, travellers diverted are distributed:

- 60% to NER (Based on volume comparison between NER and LNER)
- 40% to LNER

- 45% in Tea Tree Plaza (Based on observations. Refer to Appendix D)
- 45% in Paradise
- 10% in Klemzig

As result, the following diversion assignment matrix was obtained:

Table 20-[V diversion]

Transit diversion NER				Transit diversion LNER			
3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422
0.6	0.6	0.54	0.33	0.4	0.4	0.36	0.22

Finally, Trips assignment for the year t can be expressed as:

- [V cars]t – [V diversion]*DUt/1.22 for cars, Base Case [9]
- [V cars]t + [V diversion]*NDUt/1.22 for cars, with Transit Project [10]

- [V transit]*(dPt+NDUt) for transit [11]

Note: 1.22 is the average Car Occupancy rate between 1997-2019 (South Australian Government Data directory, 2019)

Detailed Trip Assignment Result for T.Scenario 1, 2 and 3, are shown in Appendix E.

6. Travel Time Savings and Congestion Function.

The aim of this chapter is to determine Transit Travel Times savings and Car Travel Time Savings. In addition, it is worthwhile disaggregating Travel Time Savings in the peak hour (p), inter-peak (ip) and off-peak (op).

Furthermore, given the facts that Transit Services are offered (rounded) between 05:00 am to 00:00 am (05:00 to 24:00) and transit patronage is relatively very low on weekends, Car Travel Time savings are calculated only for weekdays.

6.1. Yearly variation

SCATS traffic counts data (refer to Section 5.1) was analysed for an entire year for the following intersections:

Table 21-SCATS traffic counts data of intersections analysed

74	DEQUETTEVILLE TERRACE -NORTH TERRACE -HACKNEY ROAD
282	MAIN NORTH EAST ROAD - TAUNTON ROAD
206	MAIN NORTH EAST ROAD - SUDHOLZ ROAD
498	NORTH EAST ROAD MCINTYRE ROAD
77	PORTRUSH ROAD - PAYNEHAM ROAD
265	DARLEY ROAD - LOWER NORTH EAST ROAD
422	LOWER NORTH EAST ROAD-VALLEY ROAD

Considering the weekly volume and after filtering data errors, a common shape was observed. The following graphs are shown simply as examples:

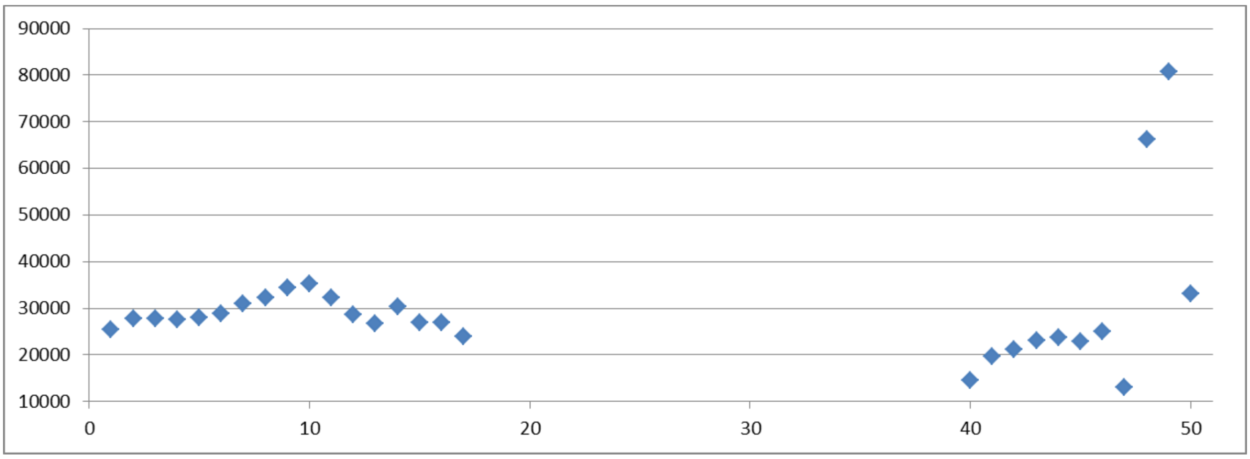

Figure 17-Weekly Volume in link 1159-74 in 2017

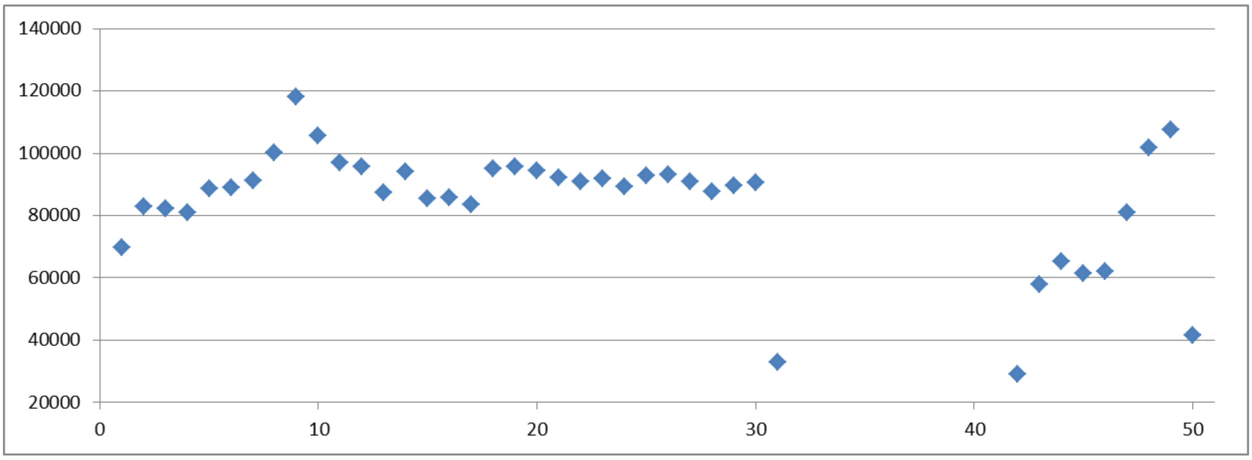

Figure 18- Weekly Volume in link 74-72 in 2017

Datasets for the entire year seem incomplete due to a type of error detected in SCATS, which are counts (for one lane in a period of 5 minutes) with values of 2046 (2^11 -2) or 2047 (2^11 -1). In addition, some points are considered atypical. Overall, in spite of observing a mild seasonality, the variation is of low relevance. Indeed, AADT is an annual average, implying that seasonal effects are neglected.

Accordingly, a constant week type was adopted, and 51 weeks per years are considered (rounding a 360-day commercial year divided 7). This assumption was made for Cars and Transit.

6.2. Weekly variation - Cars

Similar to Section 6.1, the same SCATS dataset was analysed with the following considerations:

- Data with errors filtered
- Outliers filtered (Outlier 1.5 IQR rule, refer to Glossary)
- Data ordered by weekdays (1: Sunday – 7: Saturday)

As a result, the following graph with Average Daily Traffic by weekdays divided AADT was obtained:

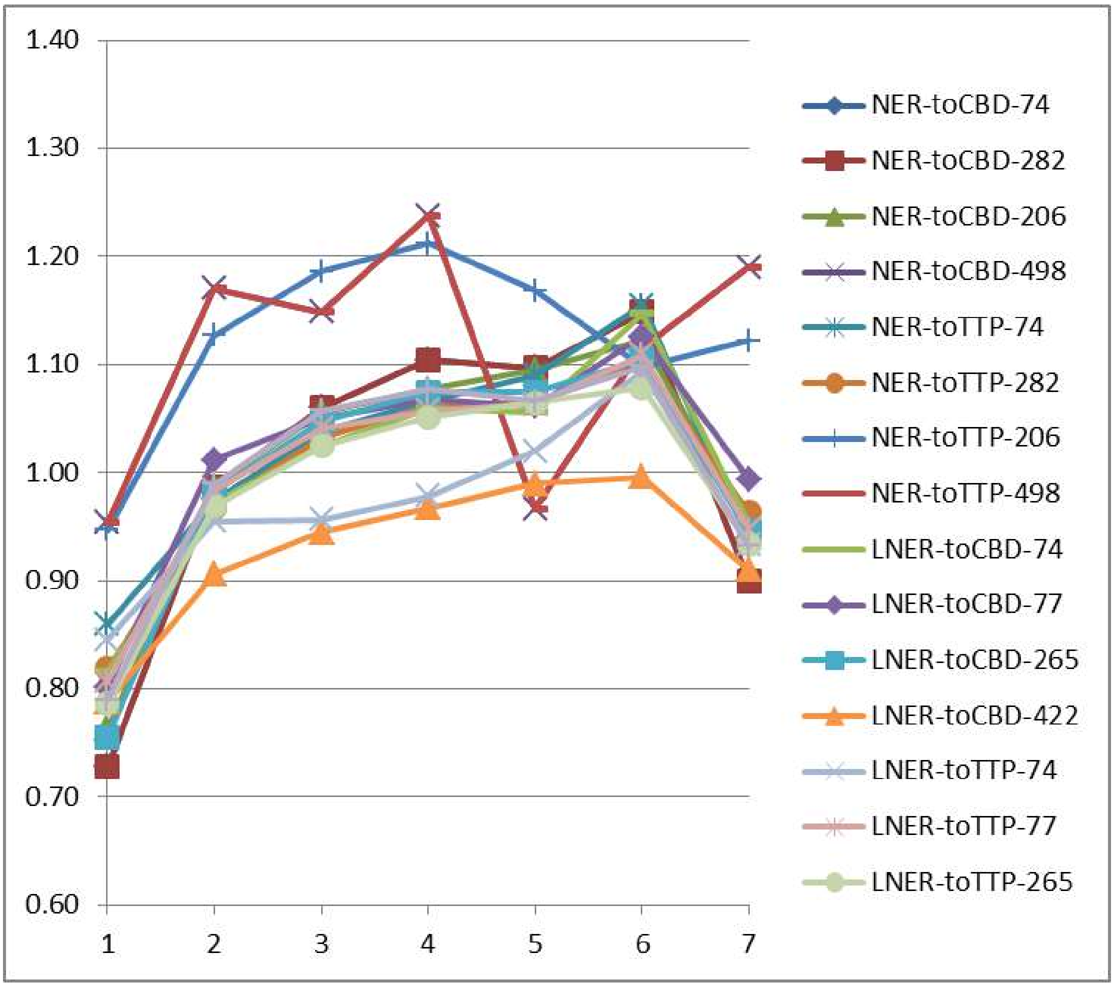

Figure 19- Average Daily Traffic by weekdays divided AADT

The data filtering still presents errors. For example, while the sum of a link should be 7, some links are above or below 7. However, a clear weekly distribution is observed. The weekly variation adopted is based on the average-adjusted of links considered (analysed above):

Table 22-Weekly variation - Cars

Weekday	Volume/AADT
Sun	0.80
Mon	1.05
Tue	1.05
Wed	1.05
Thu	1.05
Fri	1.05
Sat	0.95
Week	**7.00**

6.3. Weekly variation - Transit

Transit weekly variation is adopted from O'Bahn Boardings surveys (Department of Transport (SA), 1988):

Table 23- Weekly variation - Transit

Weekday	Patronage/dP
Sun	0.09
Mon	1.00
Tue	1.00
Wed	1.00
Thu	1.00
Fri	1.00
Sat	0.25
Week	**5.34**

6.4. Hourly variation - Cars

Similar to Section 6.1, the same SCATS dataset was analysed with the following considerations:

- Data with errors filtered
- Outliers filtered (Outlier 1.5 IQR rule, refer to Glossary)
- Data ordered by time of the day

As a result, the following graph with Average Traffic by hour divided AADT was obtained:

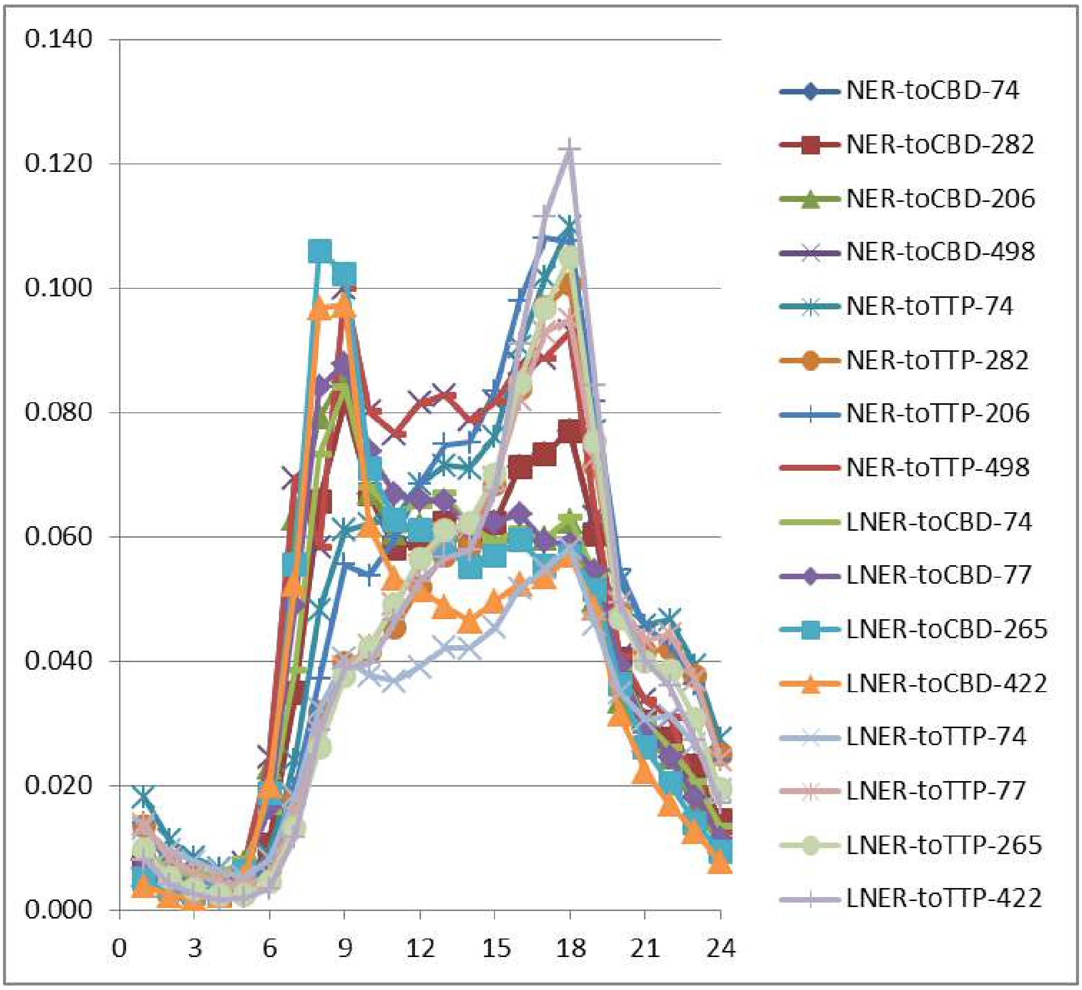

Figure 20-Average Traffic by hour divided AADT

Similar to Section 6.2, errors are detected. For example, while the sum of a link should be 1, some links are above or below 1. However, a clear hourly distribution is observed. The hourly variation adopted is based on the average-adjusted of links considered (analysed above) and the matrix will be referred as [HV-C]:

Table 24-[HV-C] Hourly variation - Cars

	to CBD	to TTP
0:00 - 1:00	0.003	0.006
1:00 - 2:00	0.002	0.003
2:00 - 3:00	0.002	0.002
3:00 - 4:00	0.002	0.002
4:00 - 5:00	0.003	0.002
5:00 - 6:00	0.009	0.004
6:00 - 7:00	0.024	0.011
7:00 - 8:00	0.039	0.018
8:00 - 9:00	0.044	0.025
9:00 - 10:00	0.034	0.024
10:00 - 11:00	0.031	0.026
11:00 - 12:00	0.031	0.029
12:00 - 13:00	0.031	0.030
13:00 - 14:00	0.030	0.031
14:00 - 15:00	0.030	0.034
15:00 - 16:00	0.032	0.040
16:00 - 17:00	0.032	0.045
17:00 - 18:00	0.034	0.048
18:00 - 19:00	0.027	0.034
19:00 - 20:00	0.019	0.023
20:00 - 21:00	0.014	0.019
21:00 - 22:00	0.012	0.019
22:00 - 23:00	0.009	0.015
23:00 - 24:00	0.006	0.010
All day	0.50	0.50

6.5. Hourly variation - Transit

Transit hourly variation is adopted from O'Bahn Boardings surveys (Department of Transport (SA), 1988). The following matrix will be referred as [HV-T]:

Table 25-[HV-T] Hourly Variation - Transit

	to CBD	to TTP
5:00 - 6:00	0.013	0.007
6:00 - 7:00	0.014	0.006
7:00 - 8:00	0.093	0.042
8:00 - 9:00	0.087	0.048
9:00 - 10:00	0.020	0.014
10:00 - 11:00	0.019	0.015
11:00 - 12:00	0.018	0.016
12:00 - 13:00	0.017	0.017
13:00 - 14:00	0.022	0.023
14:00 - 15:00	0.021	0.024
15:00 - 16:00	0.058	0.072
16:00 - 17:00	0.054	0.076
17:00 - 18:00	0.054	0.076
18:00 - 19:00	0.006	0.007
19:00 - 20:00	0.006	0.007
20:00 - 21:00	0.005	0.008
21:00 - 22:00	0.005	0.007
22:00 - 23:00	0.004	0.008
23:00 - 24:00	0.004	0.007
All day	0.5	0.5

6.6. Hourly variation - Summary

In summary, Hourly variations can be expressed as:

- [HV-C]*1.05
  for Cars in week days (Travel Time savings are not considered for weekends) [12]

- [HV-T]
  for Transit in week days (this hourly variation is only relevant for Diverted Users (DU) and New Diverted Users (NDU), which affect Car Travel Times. Hence, weekends don't need to be considered) [13]

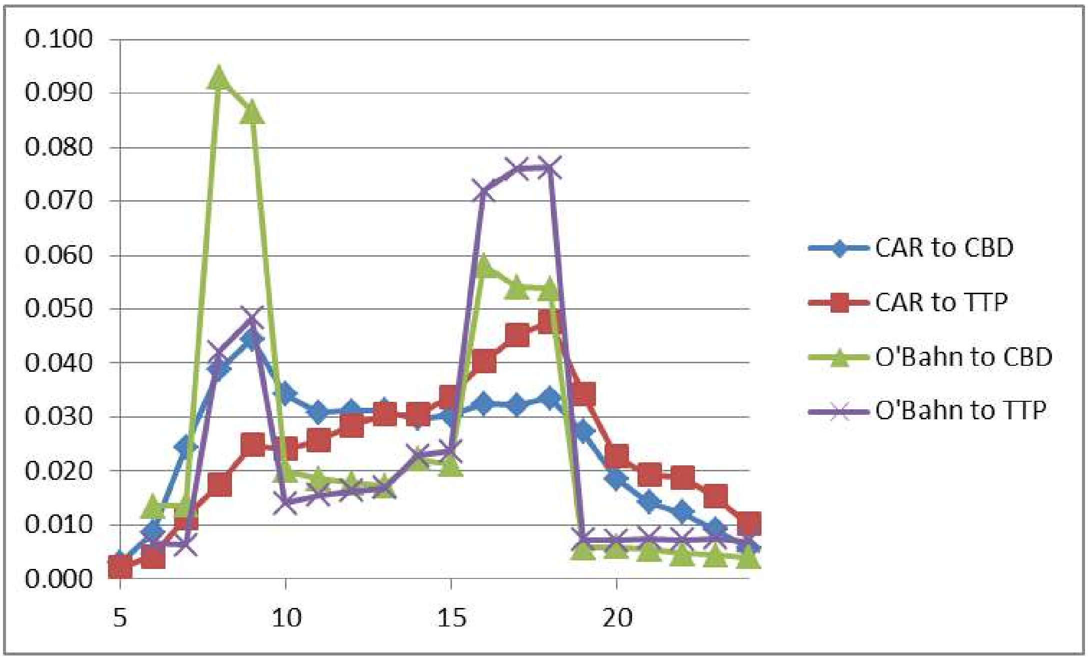

Figure 21-Hourly Variation [HV-C] and [HV-T]

In addition, results will be disaggregated as follows:

- Peak hours (suffix p):
  Weekdays, 07:00 – 09:00
  Weekdays, 15:00 – 18:00
  5 hours in total

- Inter peak hours (suffix ip):
  Weekdays, 09:00 – 15:00
  6 hours in total

- Off-peak hours (suffix op):
  Weekdays, 05:00 – 07:00
  Weekdays, 18:00 – 24:00
  8 hours in total
  Only for Transit, weekends are considered off-peak hours.

- Weekends not considered for cars.
- 00:00 to 05:00 not considered
- Holidays (in excess of 51 weeks/weekends per year) is considered of low relevance.

6.7. Congestion function - Car

In addition to the trip distribution and assignment defined in Chapter 5, a Congestion function (speed-volume relationship) is required to determine Car Travel Time savings.

The congestion function adopted is the Akcelik formula, the same as used in MASTEM (Nicholas Holyoak, 2005). However, a calibration process was performed to adjust the formula parameters.

Akcelik formula (Dowling, Singh and Cheng (1998) as cited in (Nicholas Holyoak, 2005):

$$t = t_0 + \frac{T_f}{4}\left[(x-1) + \sqrt{(x-1)^2 + \frac{8J_A x}{QT_f}}\right] \qquad v = \frac{v_0}{1 + \frac{r_f}{4}\left[(x-1) + \sqrt{(x-1)^2 + \frac{8J_A x v_0}{QLr_f}}\right]}$$

[14]

Note: t = 1/v ; to = 1/vo

- t: Travel Time (CTT)
- v: average link speed.
- to: free-flow travel time
- vo: free-flow speed.
- Tf: time period for traffic demand
- Q: link capacity in that time period
- X: Volume/Q
- JA: delay parameter
- Rf: Tf/to
- L: link length

In MASTEM the main parameters for the congestion function are listed below (provided by Professor Branko Stazic):

Table 26-Main parameters of Akcelik congestion function in MASTEM

[table removed due to copyright restriction]

The MASTEM calibrated congestion curves are shown below:

[figure removed due to copyright restriction]

Figure 22-Calibrated congestion curves in MASTEM

Thereafter, a calibration process was attempted using Bluetooth Travel Times Data and SCATS data (refer to Section 5.1). This process consisted of:

- Identification of relevant sites with Bluetooth TT measurements and Links length. Software ArcGIS Pro was used to identify and filter relevant sites (refer to Network Map in Section 5.2)
- Data collection: Bluetooth data available from 26/05/2017 to 15/06/2017 (3 weeks). Approximately 2.000.000 records (Big Data).
- Data collection: SCATS data available for the whole year (2017). Approximately 1.500.000 records (Big Data).
- Big Data processing:
  - SCATS data: text mining.
  - SCATS data: errors filtering (2046 and 2047 errors)
  - SCATS data: data mining (filters by intersection approaches, Link matching, Direction matching, Time (1 hour periods), day, weekday and week (for weekly variation analysis in previous Sections).
  - SCATS data: outliers filtering (Outlier 1.5 IQR rule)
  - Bluetooth data: text mining.
  - Bluetooth data: data mining (filters by Origin-Destination, Link matching, Direction matching, Time (1 hour periods), day.
  - Bluetooth data: data mining 2 - Travel Time measurements disaggregation by links (linear distribution based on links length adopted)
  - Bluetooth data: outliers filtering – Travel Time (Outlier 1.5 IQR rule)
  - Bluetooth data: data mining 3 – Travel Time measurements averages by link.
  - Data fusion and Integration – Combine SCATS volume data with Bluetooth Travel Time data (total 2.128 records)

The results of this process were not satisfactory. Even though some points were close to expected values, results, in general, were not coherent. It is believed that the bad quality of results is a consequence of bad quality in data, which has the following features:

- Limited data records (only 3 weeks).
- SCATS data presents errors (2046 and 2047 errors)
- SCATS data does not have Heavy Vehicle proportions or counts.
- Bluetooth measurements do not register times in intermediate sites. This explains the observations that are too long in distance and too long in time.
- Bluetooth data does not distinguish if a car stopped for some reason and then continued with its journey (e.g. fuel recharge, quick shopping, etc)
- The effectiveness of the Outlier 1.5 IQR rule is diminished when there are many errors.

As a consequence, 14 Car Travel Times Surveys were performed (refer to Appendix C). The survey basically consists of measuring the travel time between control sections. Then, in addition, the Traffic Volume is estimated (based on Volumes determined in chapter 5, and hourly variation determined in previous Sections).

Thereupon, satisfactory calibrations were possible, and only 4 sets of formulas were required. Results of the Big Data processing, Car Travel Time surveys and Calibration are shown below:

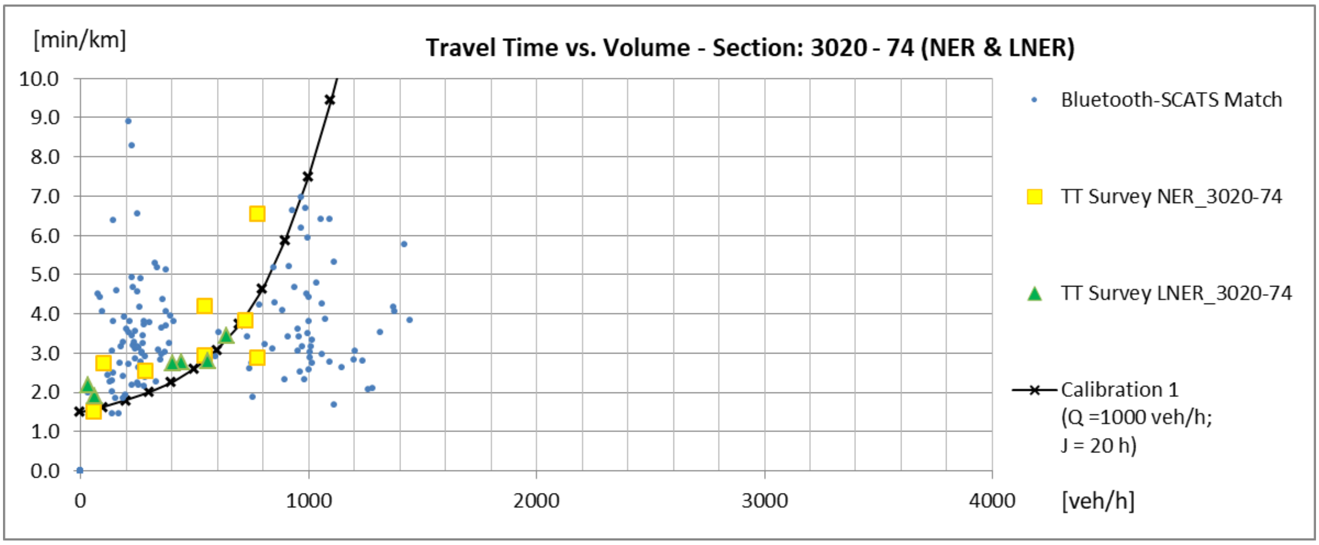

Figure 23-Travel Time vs. Volume – Section 3020-74

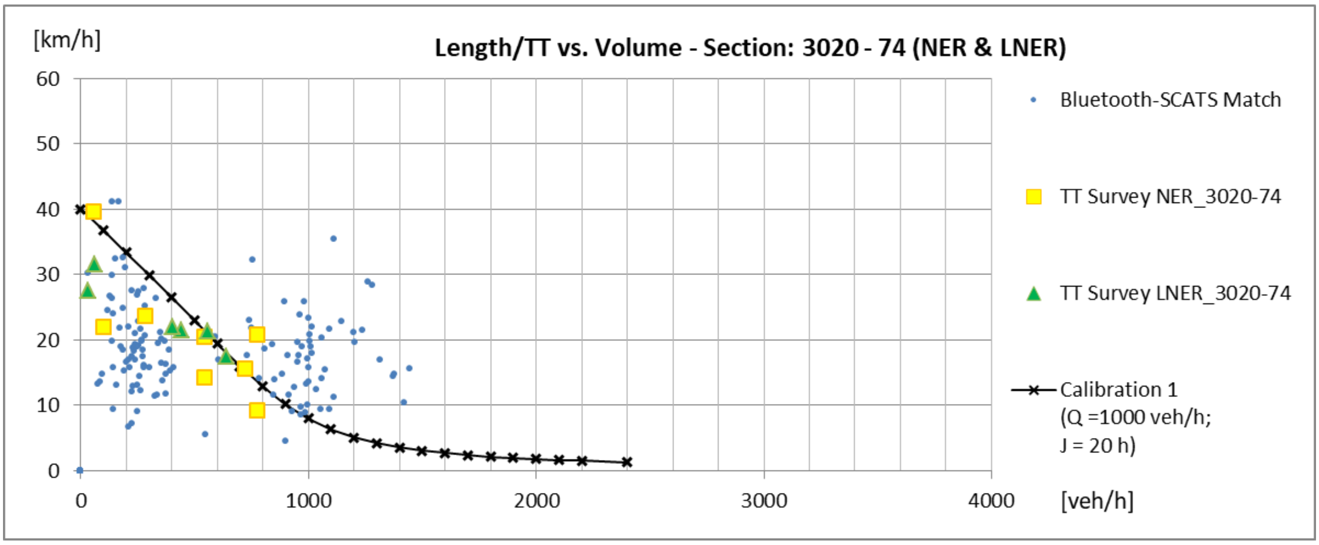

Figure 24-Normal Operating Speed vs. Volume – Section 3020-74

Table 27-Akcelik formula – Calibration 1

Calibration 1 (Q =1000 veh/h; J = 20 h)		
To	0.025	[h]
Vo	40	[km/h]
Lanes	1	[lanes]
q	1000	[veh/lane-h]
Q	1000	[veh/h]
J A	20	[h]
Rf	40	

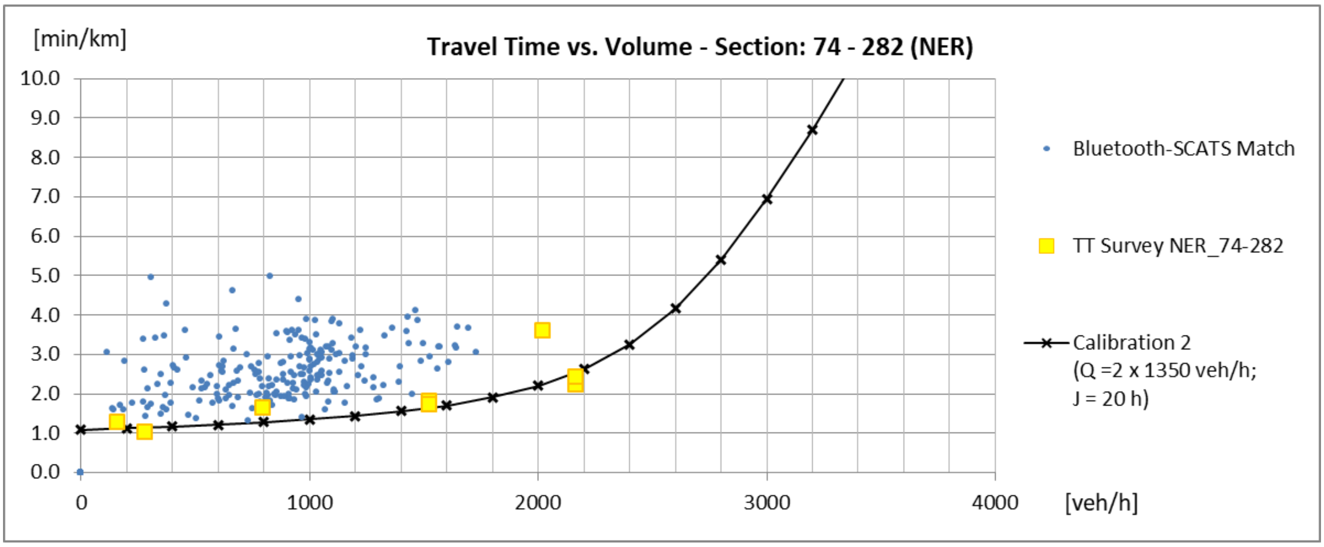

Figure 25-Travel Time vs. Volume – Section 74-282

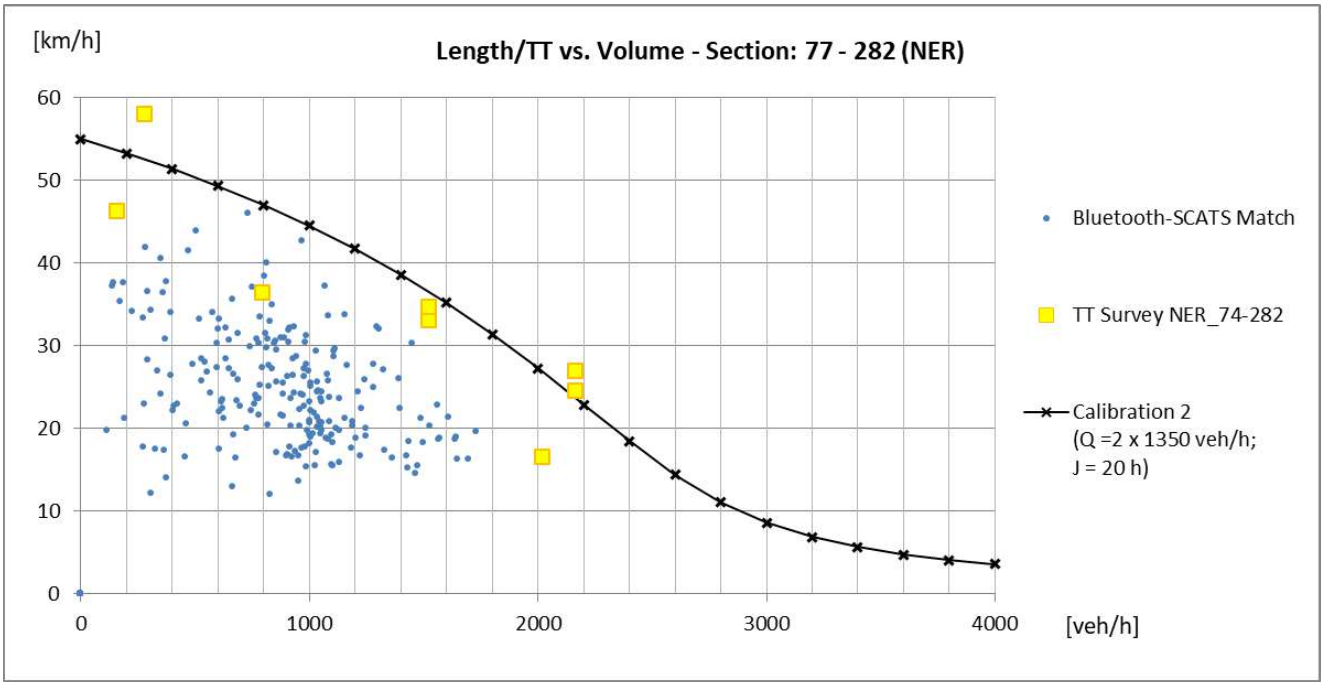

Figure 26-Normal Operating Speed vs. Volume – Section 77-282

Table 28-Akcelik formula – Calibration 2

Calibration 2 (Q =2 x 1350 veh/h; J = 20 h)		
To	0.018	[h]
Vo	55	[km/h]
Lanes	2	[lanes]
q	1350	[veh/lane-h]
Q	2700	[veh/h]
J A	20	[h]
Rf	55	

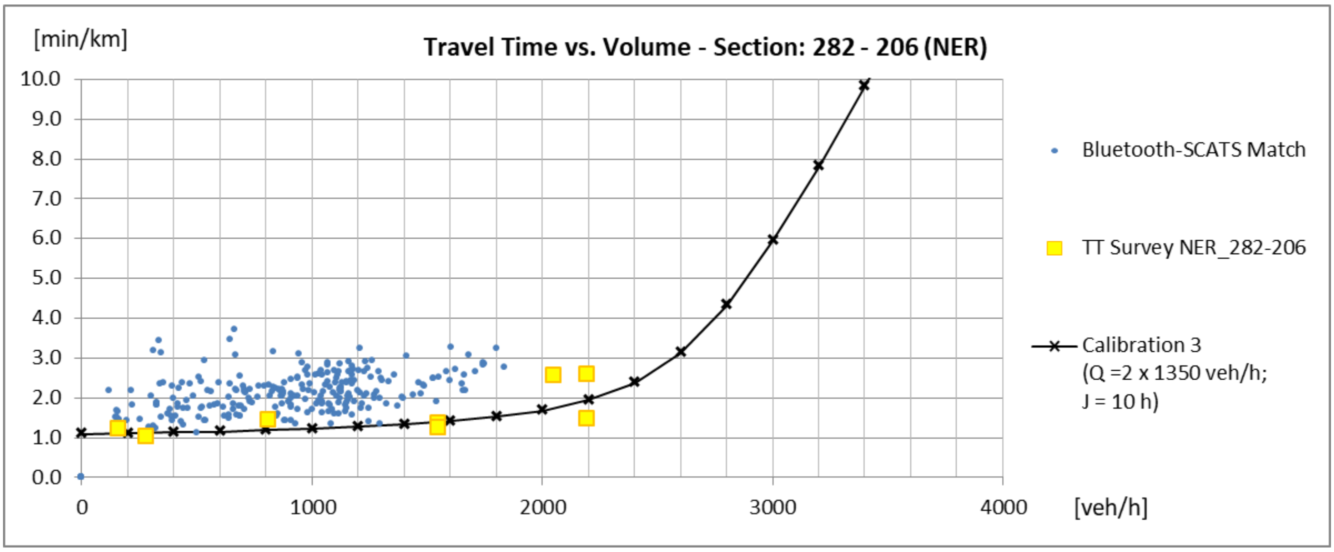

Figure 27-Travel Time vs. Volume – Section 282-206

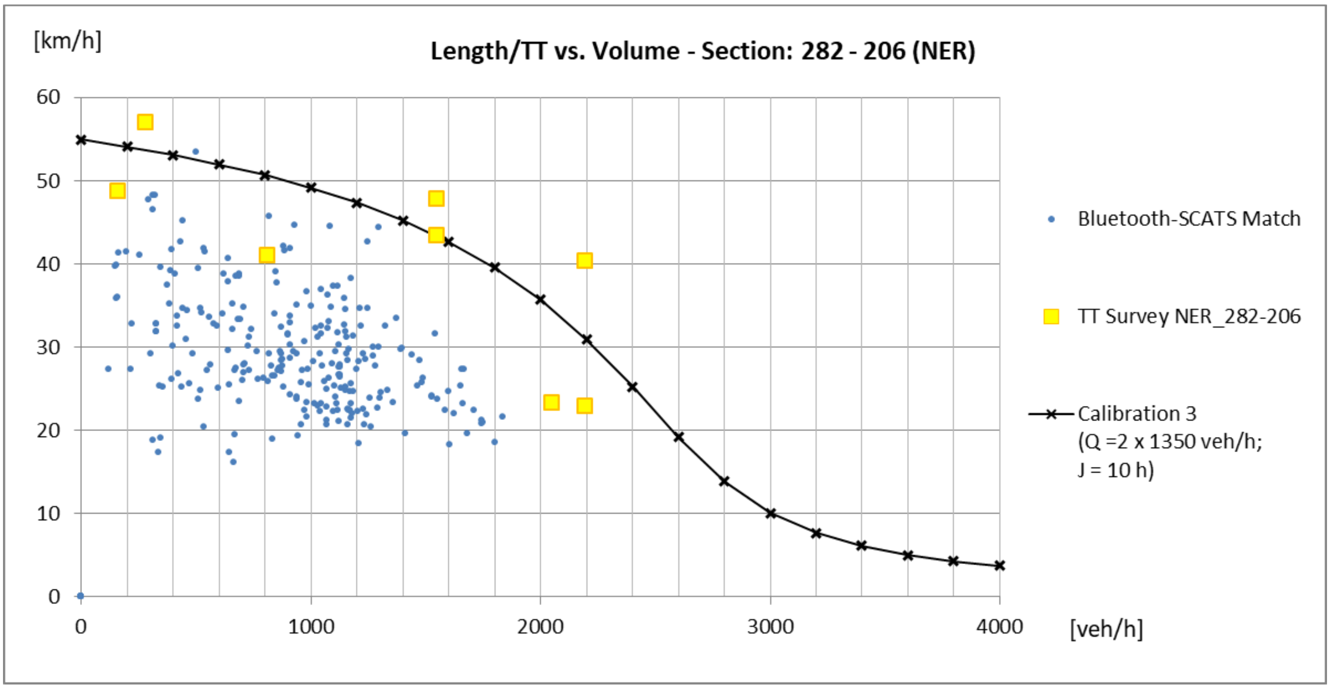

Figure 28-Normal Operating Speed vs. Volume – Section 282-206

Table 29-Akcelik formula – Calibration 3

Calibration 3 (Q =2 x 1350 veh/h; J = 10 h)		
To	0.018	[h]
Vo	55	[km/h]
Lanes	2	[lanes]
q	1350	[veh/lane-h]
Q	2700	[veh/h]
J A	10	[h]
Rf	55	

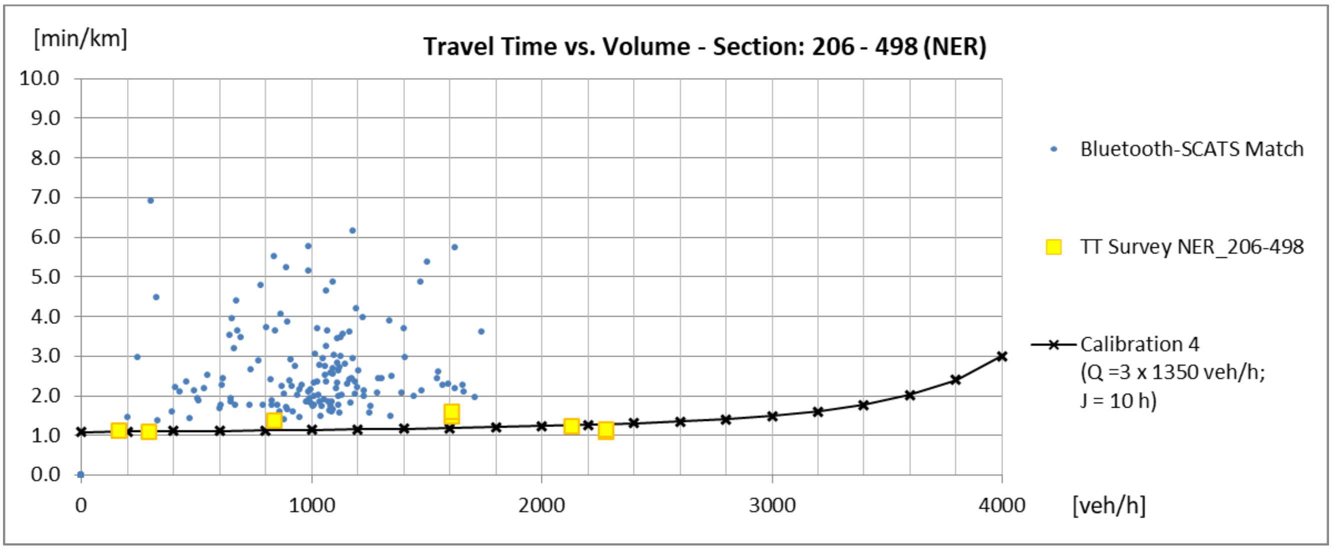

Figure 29-Travel Time vs. Volume – Section 206-498

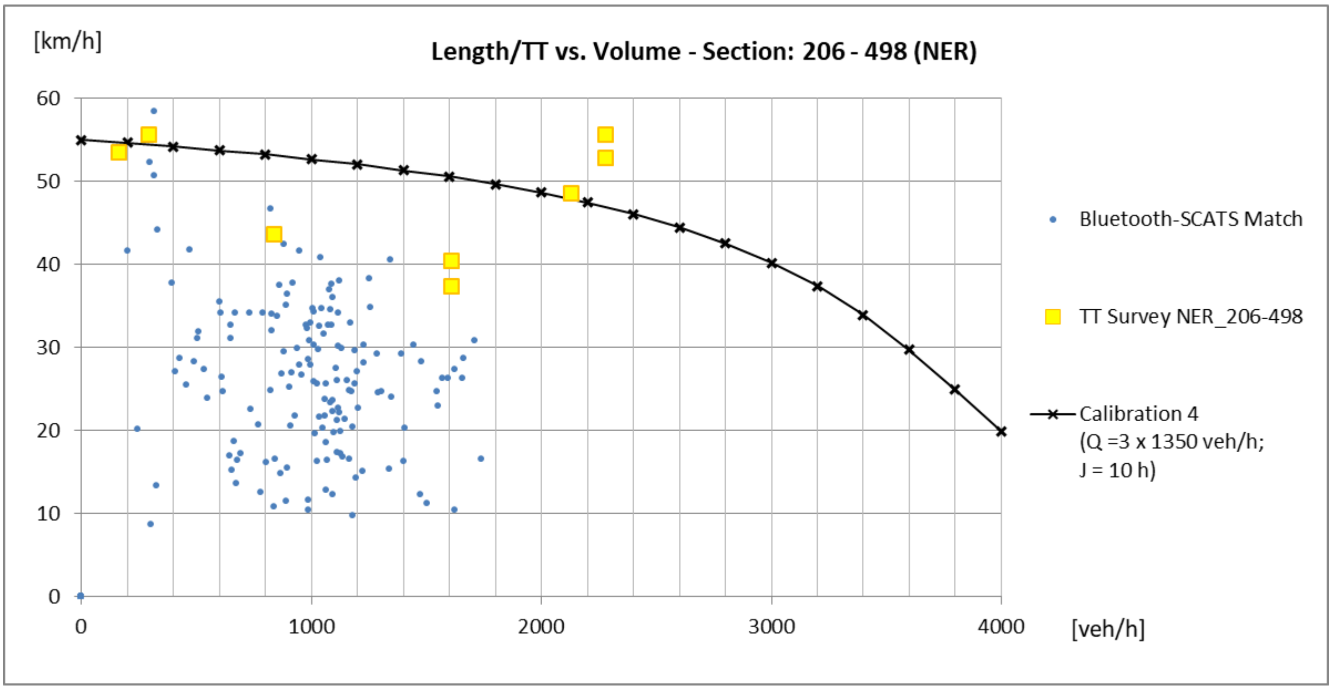

Figure 30-Normal Operating Speed vs. Volume – Section 206-498

Table 30-Akcelik formula – Calibration 4

Calibration 4 (Q =3 x 1350 veh/h; J = 10 h)		
To	0.018	[h]
Vo	55	[km/h]
Lanes	3	[lanes]
q	1350	[veh/lane-h]
Q	4050	[veh/h]
J A	10	[h]
Rf	55	

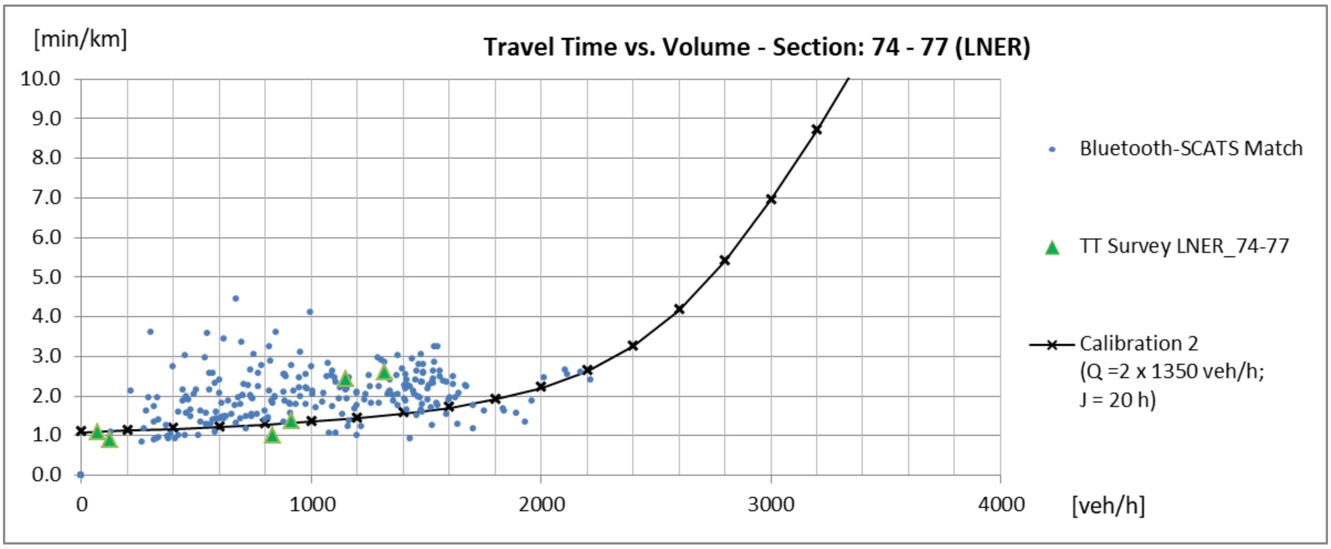

Figure 31-Travel Time vs. Volume – Section 74-77

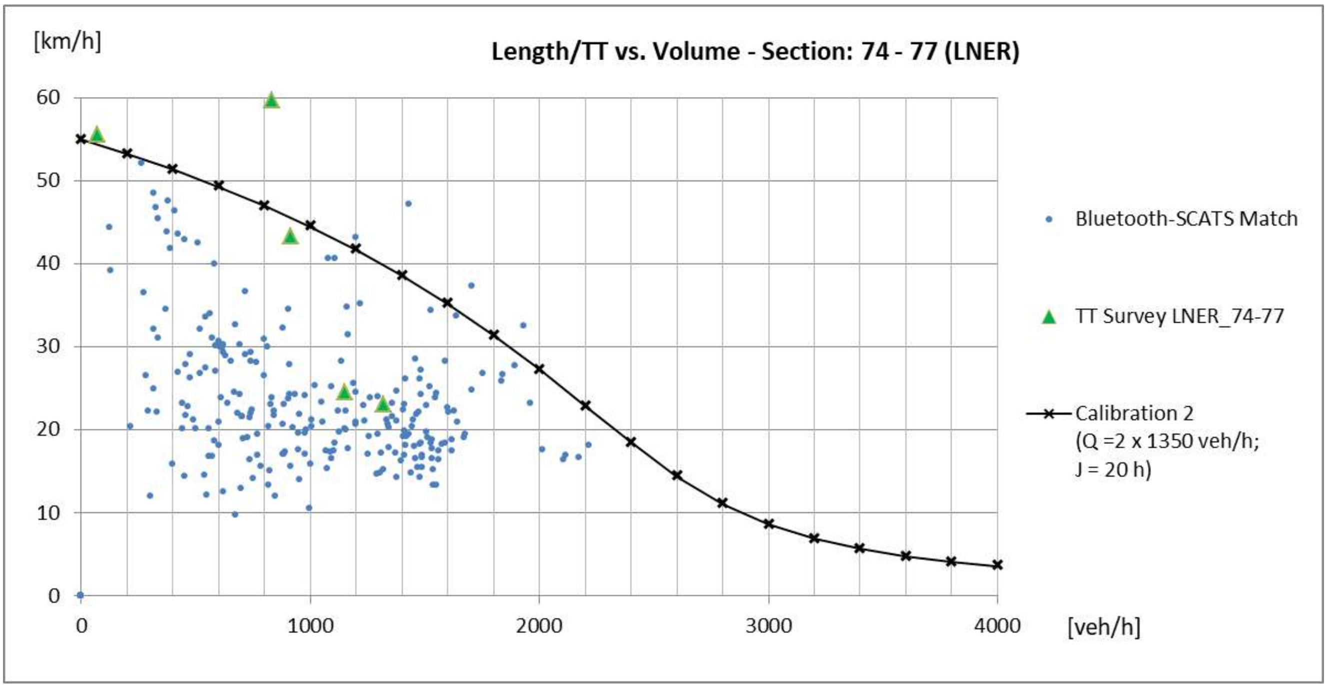

Figure 32-Normal Operating Speed vs. Volume – Section 74-77

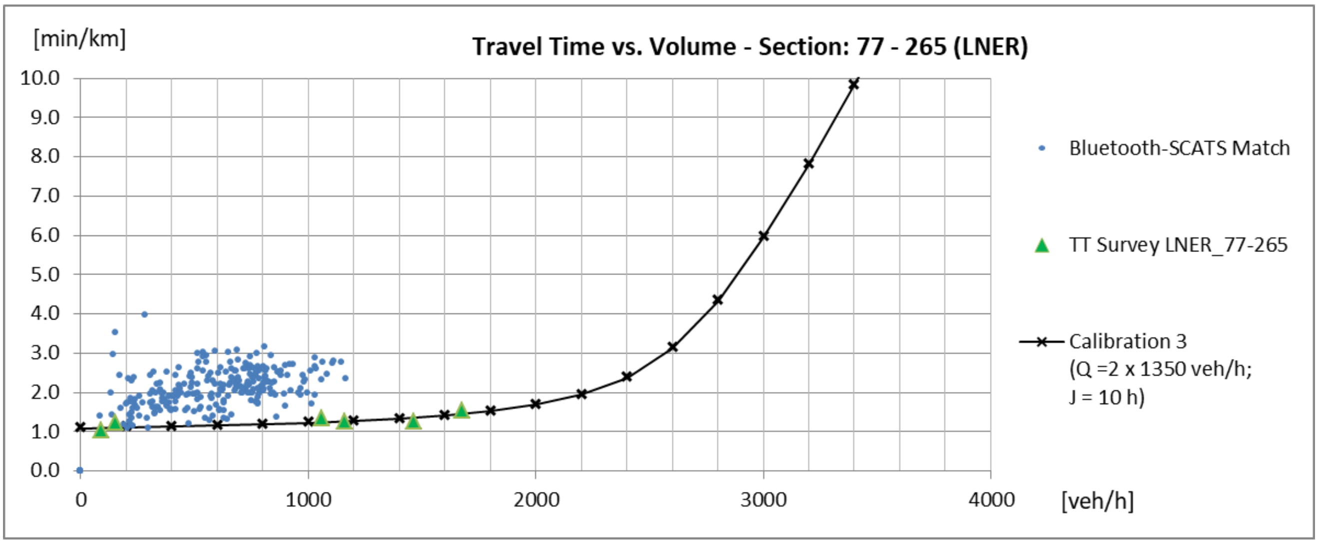

Figure 33-Travel Time vs. Volume – Section 77-265

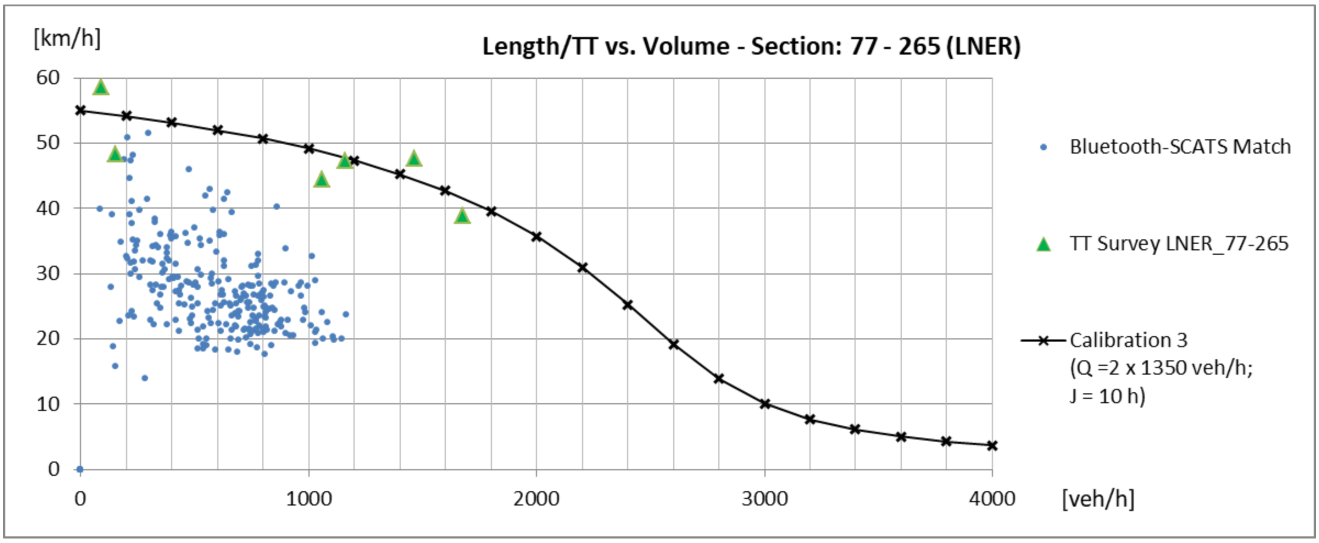

Figure 34-Normal Operating Speed vs. Volume – Section 77-265

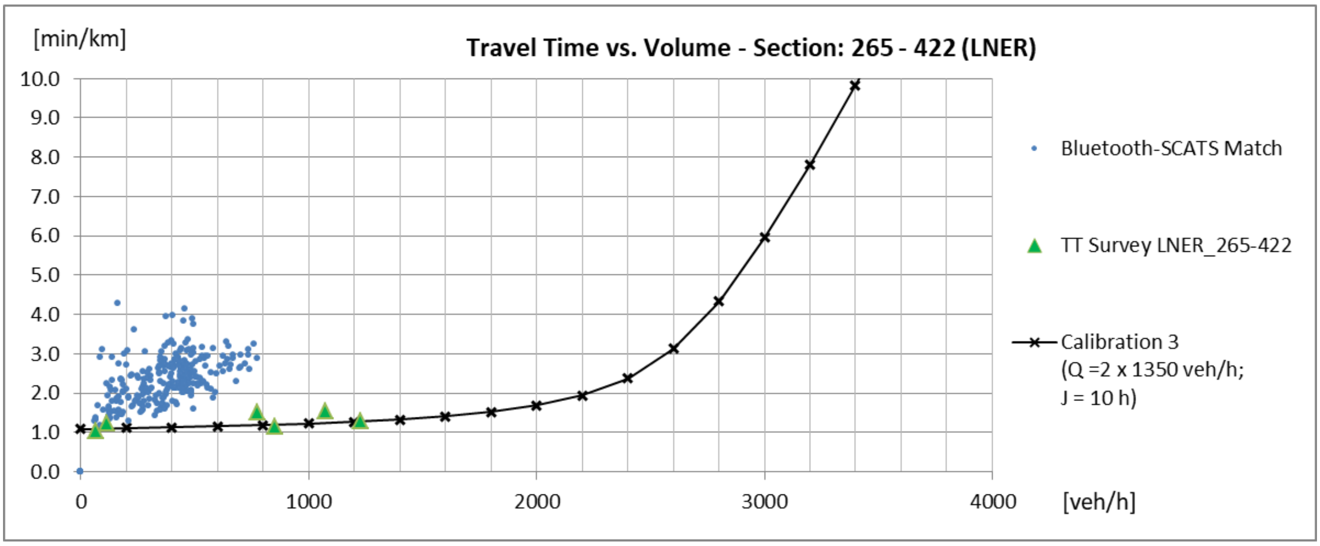

Figure 35-Travel Time vs. Volume – Section 265-422

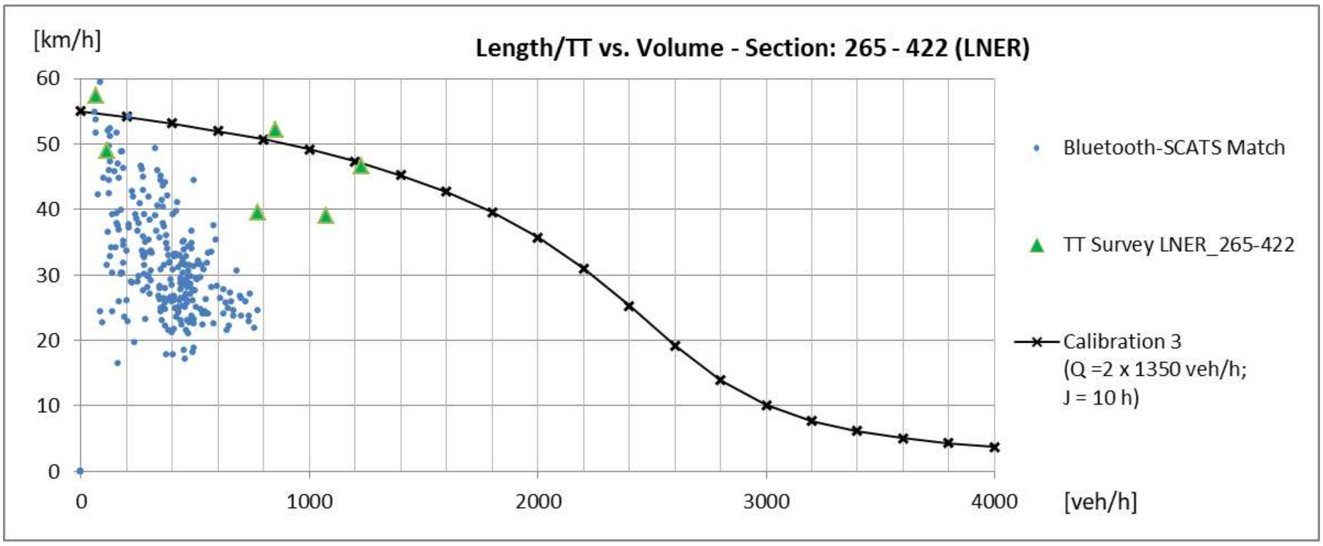

Figure 36-Normal Operating Speed vs. Volume – Section 265-422

Even if the formula is the same as used in MASTEM, and some of the parameters adopted are the same (such as the link capacity per lane q), these calibrations have the following characteristics:

- Routes are simplified into 4 links for NER and 4 links for LNER.
- The links division was based on features of the links, dividing them into sections with roughly similar road features, such as the number of lanes, divided/undivided and CBD-area/North-East-suburbs.

- Links are relatively very long and include many signalized intersection. Therefore, Travel Times include Stopped time delay, Approach delay and Travel time delay. Similarly, the formula calibrations produce Normal Operating Speed for links (instead of Average Link Speed).
- The formula calibrations are valid only for this network's links. In other words, the Akcelik calibrations detailed in this section are not suitable for general application.

Finally, Car Travel Times [CTT] for a link with a certain volume [Vh], calculated with the relevant Akcelik formula calibration, can be expressed as:

[CTT] = f([Vh])   or

[CTT] ij = f([Vh]ij)   [15]

* Units in [min/km-veh]

6.8. Transit Travel Times

Based on present-day schedules, O'Bahn bus lines need 18 minutes to travel between CBD Area to Tea Tree Plaza (TTP) (Adelaide Metro, 2021). Thanks to the ROW-A in the O'Bahn, travel times are very reliable. Indeed, buses can speed up or wait some time in the stations in order to comply with the timetable within the minute. Even if the first (or last) 450 metres from the CBD area, before entering the guided-busway are exposed to traffic congestion, Bus timetable in the Modbury corridor is still very reliable. In fact, it was observed buses having to wait in stations a few minutes, even in peak hours (refer to Appendix D)

Accordingly, travel times in the O'Bahn between stations are adopted as follow:

- CBD-Klemzig: 9 min.
- Klemzig-Paradise: 3 min.
- Paradise-TTP: 6 min.
- Normal Operating Speed (vo): 40 km/h (even if buses can reach up to 85km/h, Normal Operating Speed is reduced by Stopped time delay, Approach delay and Travel time delay)

This Normal Operating Speed is adopted for Transit Projects, except for improved performance versions and heavy rail options.

Timetables for Bus routes in NER and LNER were investigated to determine the Normal Operating Speed outside the Modbury Corridor:

- Normal Operating Speed (vo): 26 km/h (due to the fact that the number of stops is highly increased, approach delays are multiplied and travel speed are much lower)
- There is no considerable difference between peak hours and off-peak hours. Moreover, buses generally need to stop in off-peak hours to comply with the timetable.

Thereupon, this is the adopted Normal Operating Speed for the Base Case. It is noticed that travel times would increase (or vo decrease) if the Transit Project were not constructed, nevertheless the effect of O'Bahn routes driving on NER/LNER in the Base Case is considered of low relevance and would exceed the scope of the model. As a result, Transit Travel Time savings will be slightly underestimated.

Finally, heavy rail and improved performance options (options that require a tunnelled section in the CBD Area) are assumed to be able to reduce delays producing a 25% higher Normal Operating Speed, adopting:

- Normal Operating Speed (vo): 50 km/h

Equally important, Public Transport options with different timetable features involve different time penalties. Time penalties account for the time required to wait for the bus, bus transfers, access to the station, anxiety/attention required while using the service, etc. Time penalties are calculated based on ATAP Guidelines - M1 Public Transport - Supporting Technical Report - Public Transport Parameter Values (Transport and Infrastructure Council, 2018), and details of considerations are listed below:

AE = access/egress 'out of vehicle' walk time

SI = service interval (mins between departures)

TP = transfer penalty (number by type)

TW = transfer connection walk and wait time

IVT = in-vehicle time (mins)

IVTCWD= in-vehicle time in crowded conditions (multiplier should be 'net' i.e. minus 1)

REL= reliability measure

Table 31-Transit Time Penalties - Summary of travel time multipliers (Transport and Infrastructure Council, 2018)

[table removed due to copyright restriction]

Table 32- Transit Time Penalties Adopted

	Do nothing		Transit Project		
[min]	Peak	Interpeak	Peak	Interpeak	Comments
AE					No substantial difference
SI	1.5	7.5	1	5	
TP	6	6	4	4	
TW					No substantial difference
REL	5	0	0	0	
IVT/IVTCWD					Calculated separately
Total Penalties	12.5	13.5	5	9	

In summary, Transit Travel Times [TTT] for a link, can be expressed as:

[TTT] = [9’, 3’, 6’] * vo / 40km/h + Total Penalties

* Units in [min/passenger]

6.9. Travel Time Savings calculations

In summary, Travel Time can be presented in the following process with matrix expression:

1) Volume matrixes (Section 5.4) **[V] i**:

➢ [V cars]t – [V diversion]*DUt/1.22	for cars, Base Case	[9]
➢ [V cars]t + [V diversion]*NDUt/1.22	for cars, with Transit Project	[10]
➢ [V transit]*(dPt+NDUt)	for transit	[11]

* Units in [Veh/day] or [passengers/day]

2) Hourly Volume matrixes (Section 6.6) **[Vh] ij**:

➢ [V] x [HV-C]*1.05	for cars	[16]
➢ [V] x [HV-T]	for transit	[17]

* Units in [Veh/hour] or [passengers/hour]

3) Travel Times in a Link per week

➢ CTT = Σ ([Vh]ij * [CTT]ij * [L cars]i) * 5 * 1.22	for cars	[18]
➢ TTT = Σ ([Vh]ij * [CTT]ij) * 5.34	for transit	[19]

*Notes:

For cars, 5 weekdays considered. No weekend TT savings accounted (Section 6.6).

1.22 [p/veh] is the car occupancy rate (Section 5.4).

For transit, the whole week is considered for TT savings (Section 6.6)

CTT and TTT Units in [h/week]

If multiplied by 51 weeks (Section 6.1), CTT and TTT units will be in [h/year]

4) Finally, savings are calculated as:

- CTT savings = CTT of the transit option – CTT of the base case [20]
- TTT savings = TTT of the transit option – TTT of the base case [21]

The following graphs illustrate the Travel Time savings results:

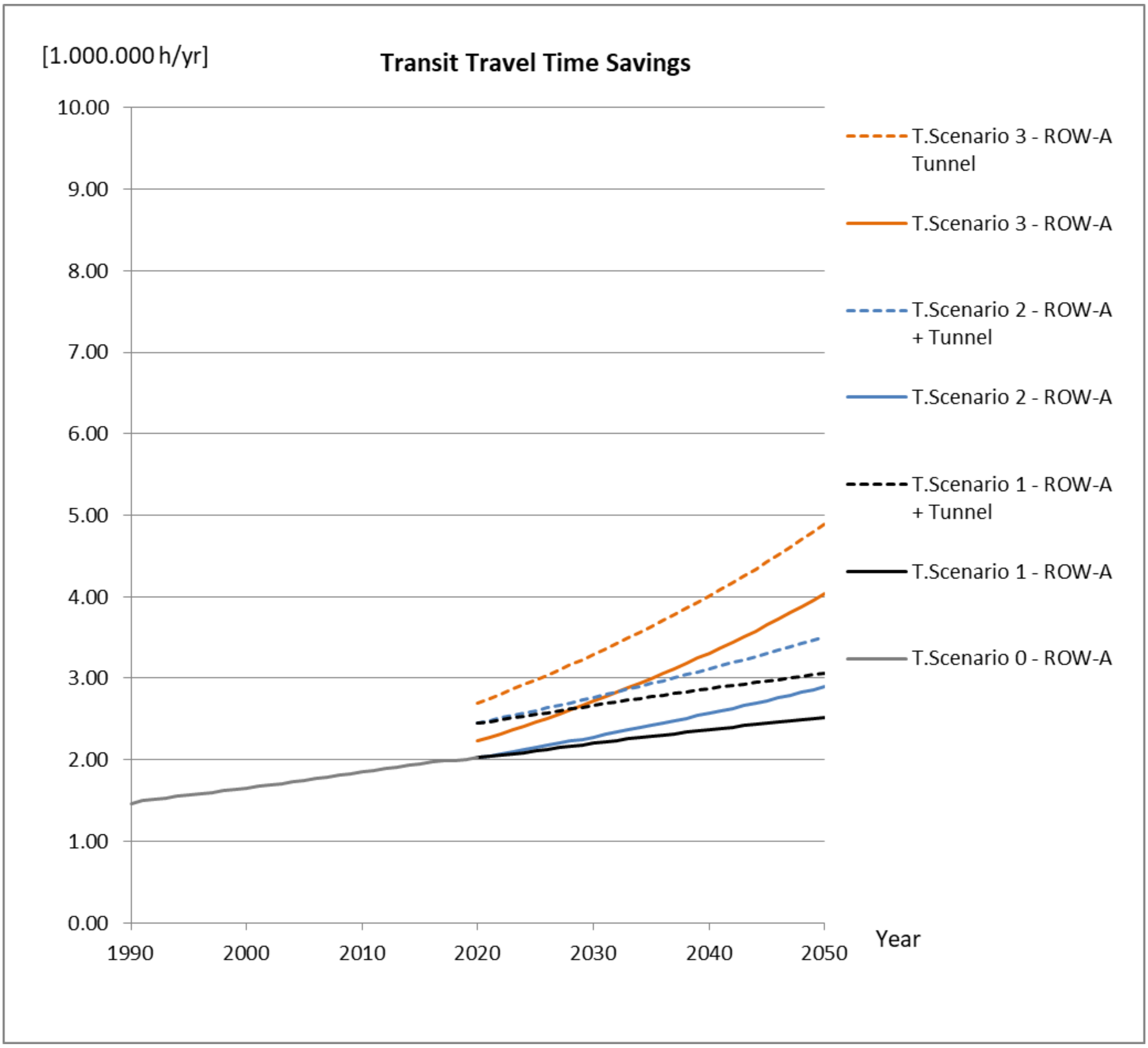

Figure 37-Transit Travel Time Savings

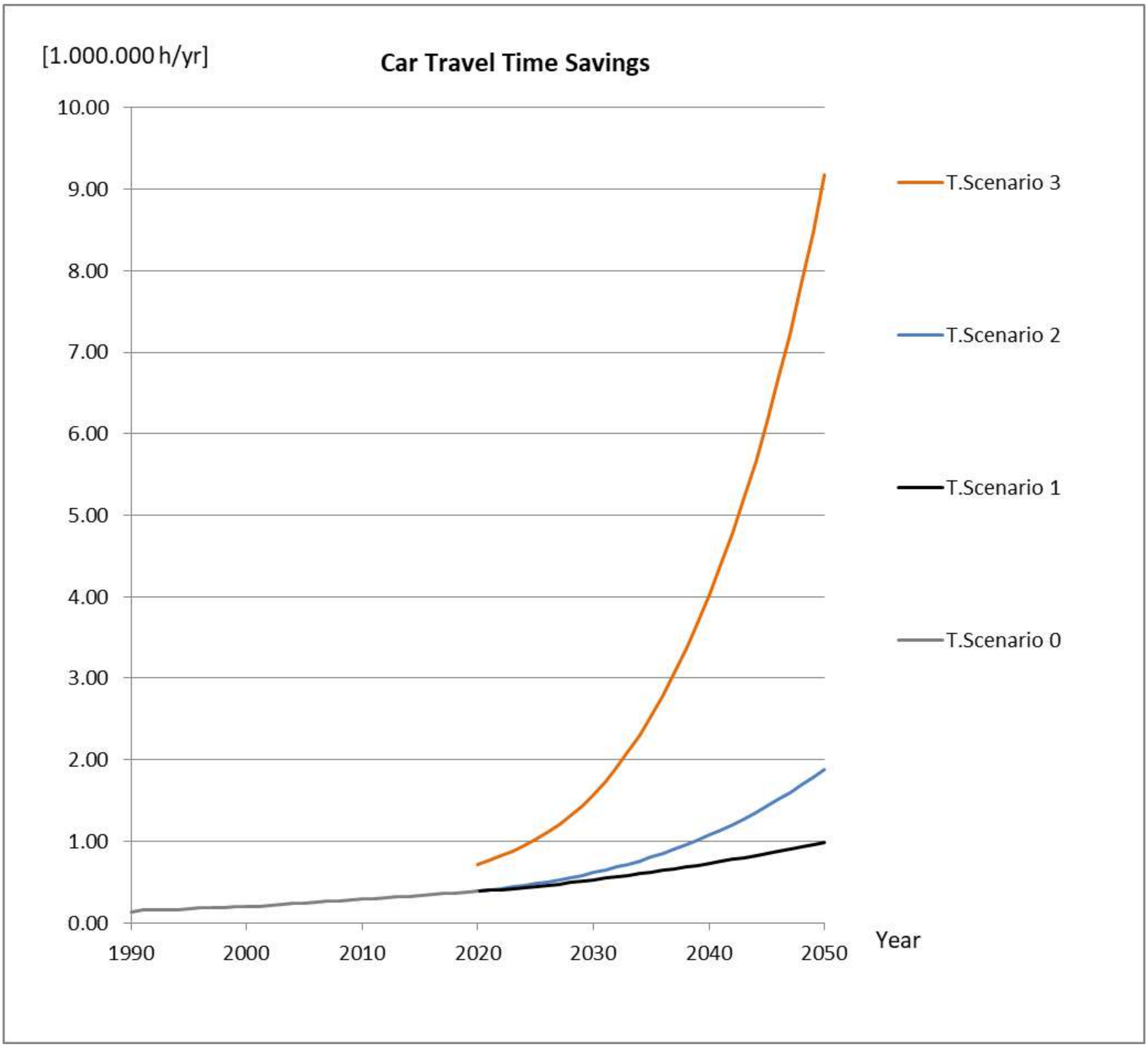

Figure 38-Car Travel Time Savings

It can be observed that the travel time savings generated for car users are less important with lower car congestion levels (e.g. periods 1990-2020). Then, it grows much quicker than TTT savings with high patronage levels and high car congestion levels.

In other words, Benefits to car users (or congestion reduction benefits), generated by a transit project, can be more important than Transit Travel Time savings in a network with high congestion levels and increased patronage.

This shape, or savings forecast, is heavily influenced by the congestion function adopted, a function that required a huge amount of effort in calibration.

Moreover, the model is assuming roads-network conditions fixed for NER and LNER (i.e. no transport project dedicated to reducing congestion such as overpass, freeway, etc.)

Furthermore, Travel Time Savings can be disaggregated in saving at Peak Hours (suffix p), Inter-peak Hours (suffix ip) and Off-peak Hours (suffix op). Then, different VOT (Value of Time) can be used, and benefits can be disaggregated for different time periods.

7. Evaluation Parameters.

The methodology adopted is BCA based on NPV and BCR with Real discount rates. Therefore, all values used for calculations are updated to December2020-AustralianDollars using CPI indexes (All Groups CPI-Australia) (Australian Bureau of Statistics, 2021).

The evaluation parameters were discussed and revised by Prof. Dr. Derek Scrafton (University of South Australia), who in turn discussed and revised the parameters adopted with other experts in the field of transport planning, such as Dr. David Bray and Dr. Peter Tisato. In the end, the following parameters adopted are considered reasonable.

7.1. Evaluation period

- 1990 to 2020 for Ex-Post Evaluation
- 2020 to 2050 for Ex-Ante Evaluation

7.2. Interest rate

Two different real interest rates r are considered:

- r = 7%
- r = 4% (for sensitivity)

7.3. Transit Mode options considered

According to Section 3.1:

Table 33-Transit Mode Options considered

Evaluation	Alternatives	
Post-Completion (Ex-post)	0	Do nothing (Base Case)
Post-Completion (Ex-post)	1	Bus Rapid Transit (O'Bahn)
Future-Project (Ex-Ante)	2	Do nothing (Base Case)
Future-Project (Ex-Ante)	3	Bus Rapid Transit (O'Bahn)
Future-Project (Ex-Ante)	4	Bus Rapid Transit 2 (O'Bahn)
Future-Project (Ex-Ante)	5	Light Rail Rapid Transit
Future-Project (Ex-Ante)	6	Light Rail Rapid Transit 2
Future-Project (Ex-Ante)	7	Heavy Rail Rapid Transit
Future-Project (Ex-Ante)	8	Heavy Rail Rapid Transit Electric
Future-Project (Ex-Ante)	9	Heavy Rail Rapid Transit Electric 2

7.4. Transport scenarios considered

According to Section 5.1:

- T. Scenario 0: Transport demand for Ex-Post analysis is based on available records.
- T. Scenario 1: Transport growth for Ex-Ante is based on population projections for Adelaide (avg. rate 0.74%). Mode Choice (or Modal split) assumed to remain the same. This is considered the best available estimation.
- T. Scenario 2: Transport growth rate increased. Adopting the average growth rate of the North-East suburbs of the last 20 years (rate adopted 1.2%). Mode Choice (or Modal split) assumed to remain the same. This is analysed for sensitivity, and considered a realistic scenario.
- T. Scenario 3: Transport growth rate and Transit slip increased. 2% growth rate adopted and 10% increase in transit patronage, being new diverted users. This is analysed for sensitivity. The aim of this scenario is to evaluate results with a high increment in the demand.

In addition, just for reference, the table below shows the transit patronage increment, in one lane, at peak hour, relative to 2020, for different periods:

Table 34-Patronage Increment in different transport scenarios

Year	Passengers Volume: Peak Hour & P.Direction [p/h]	
1990	2374	90%
2020	2638	100%
2050 Tr.Sc.1	3289	125%
2050 Tr.Sc.2	3772	143%
2050 Tr.Sc.3	5256	199%

7.5. Value of Time and Travel Time Savings Benefits

Value of Time (VOT) was adopted from ATAP Guidelines - M1 Public Transport - Supporting Technical Report - Public Transport Parameter Values (Transport and Infrastructure Council, 2018, p. 20):

- VOT for off-peak periods: 12.86 [$/h]
- VOT for inter-peak peak periods: 15.28 [$/h]
- VOT for peak periods: 17.58 [$/h]
- VOT for peak periods2*: 25.00 [$/h]

*VOT for peak periods2 is based on 50% (roughly) of the average wage in Greater Adelaide (Australian Bureau of Statistics, 2016). This higher VOT is used for sensitivity and will be referred as "High IVT Value".

Thereafter, Travel Time Savings Benefits calculation (as noted in Section 4.9) can be expressed as follows:

- CTTp savings * 17.58 (or 25.00 for sensitivity analysis)
- CTTip savings * 15.28
- CTTof savings * 12.86
- TTTp savings * 17.58 (or 25.00 for sensitivity analysis)
- TTTip savings * 15.28
- TTTof savings * 12.86

7.6. Capital Costs

According to Section 3.3, capital costs for Transit Mode Options are listed below:

Table 35-Transit Mode Options - Capital Costs

Alternatives		Total Capital Cost [A$M]
0	Do nothing (Base Case)	0
1	Bus Rapid Transit (O'Bahn)	312
2	Do nothing (Base Case)	0
3	Bus Rapid Transit (O'Bahn)	312
4	Bus Rapid Transit 2 (O'Bahn)	612
5	Light Rail Rapid Transit	1005
6	Light Rail Rapid Transit 2	1305
7	Heavy Rail Rapid Transit	1401
8	Heavy Rail Rapid Transit Electric	1545
9	Heavy Rail Rapid Transit Electric 2	1545

Considering that Capital Costs are estimations based on Benchmark Costs, it is assumed to have a risk of 30% of Cost overrun. This risk will be simply presented next to NPV to evaluate how much the NPV could change with costs overruns.

7.7. Residual Value

Assuming a very conservative lifespan of 45 years (even if major infrastructure project may reach around 70 years lifespan with good maintenance), and adopting a linear depreciation model:

Residual Value adopted: 30% of Initial Capital Costs (years remaining at the end period divided lifespan).

In O'Bahn past evaluation (Refer to Section 2.7) residual value rates between 30% to 40% were considered.

7.8. Transit Operation Costs and Transit Fare Revenue

According to Section 2.6, Transit operation Costs and Fare were adopted from *The Financial Cost of Transport in Adelaide: estimation and interpretation* (Bray, 2013, p. 158). Cost and Fare per boarding (updated to Dec.2020) were adopted. In addition, the relative difference between Light Rail Operating Costs and Heavy Rail Operating Costs is based on *Comparing Operator and Users Costs of Light Rail, Heavy Rail and Bus Rapid Transit Over a Radial Public Transport Network* (Alejandro Tirachini, 2009). As a result, concerning Rail operating costs adopted (Bray, 2013, p. 158) it was disaggregated in Light Rail (with -10% costs) and Heavy Rail (with +10% costs).

Operating Costs adopted:

- 4.77 [$/boarding] for Bus
- 8.70 [$/boarding] for Light Rail
- 10.63 [$/boarding] for Heavy Rail

Fare revenue adopted:

- 1.47 [$/boarding]

7.9. Option and Non-Use value

Values were adopted from ATAP Guidelines - M1 Public Transport (Transport and Infrastructure Council, 2018, p. 40):

- 74.15 [$/household]
- 129.48 [$/household] for the improved performance versions

Secondly, the population affected is based on nearby suburbs. Even if not all the population considered is within a walking distance, it is noticed that Park ‘n’ Ride facilities are widely used, increasing the reach of beneficiaries. Similarly, the population affected by a reduction in congestion and traffic volumes in NER and LNER are considered beneficiaries as well.

To simplify the process, only the Councils that the O'Bahn is crossing are considered (Local Government Association of South Australia, 2021):

Councils within Transit Project catchment area	Population (2018)	Households
City of Tea Tree Gully	99,694	39,878
City of Campbelltown	51,469	20,588
City of Port Adelaide Enfield	126,120	50,448
City of Norwood Payneham & St Peters	36,750	14,700

The number of households is calculated by adopting 2.5 [people/house] based on the Greater Adelaide Census (Australian Bureau of Statistics, 2016).

Then, the Option and Non-Use value is calculated by multiplying the total amount of households with the relevant adopted value.

7.10. Environmental costs reduction

Environmental costs are calculated based on ATAP Guidelines – M5 Environmental Parameter values (Infrastructure and Transport Ministers, 2020, p. 9):

Table 36- Environmental unit costs (at December 2019): urban passenger transport (Infrastructure and Transport Ministers, 2020)

[table removed due to copyright restriction]

Accordingly, Environmental costs were calculated for relevant Transport Modes:

Table 37-Environmental costs adopted

E.Cost	[$/1000 veh-km]	[$/1000 p-km]	[$/1000 p-km]	[$/1000 p-km]
	Car	Bus	O'Bahn	Rail
Air Pollution	24	25	9	4
Greenhouse gas	17	9	5	0.5
Noise	7	2	2	2
Soil and Water	2.9	3.6	3.6	0.8
Biodiversity	0.7	0.6	0.6	0.01
Nature and landscape	0.4	0.1	0.1	0.1
Additional urban/ barrier effects	5.1	1.6	1.6	1.6
Upstream/ downstream costs	27	14	14	9.1
Total (Dec-2019)	84.10	55.90	35.90	18.11
Total (Dec-2020)	84.82	56.38	36.21	18.27
	Car	Bus	O'Bahn	Rail

Thereupon, Environmental costs reduction is calculated (as noted in Section 4.9) considering the relevant matrix and relevant E.Cost for Cars/Transit/T.Scenario/Base Case:

$$\text{Environmental costs reduction} = \Sigma\ ([V]i * [L]i * E.Cost) - \Sigma\ ([V]i * [L]i * E.Cost')_{\text{base case}} \qquad [22]$$

7.11. Car operation savings

Car operation cost is based on Medium vehicle running costs as calculated by RACV (Royal Automobile Club of Victoria, 2019). This cost considers:

- 15.000 km travelled / year
- Vehicle selected: top-selling Medium vehicle
- Standing costs included (depreciation, on-road costs, interests, registration, insurance, memberships and licence fees)
- Depreciation considering average after 5 years.
- On-Road costs including stamp duty, charges and compulsory third party insurance.
- Running costs considers:
  - Average fuel price
  - One set of tyres renewal
  - Service and repairs

As a result, the Car operation cost adopted is:

- 0.71 [$/veh-km]

It is considered that car ownership costs and accident costs (hence, savings or reduction) are included in the cost adopted, seeing that depreciation, insurance and other costs are included.

Finally, Car operation cost savings calculation (as noted in Section 4.9) can be expressed as follows:

([V diversion]i * [L cars]i * (DUt + NDUt)/1.22) * 0.71 [23]

8. BCA Results.

8.1. T.Scenario 1

Considering the T.Scenario 1, normal VOT, Discount rate 7% and 4%, the results are assumed to produce the best results. These results will be compared with BCR obtained in the past evaluations of the O'bahn.

Table 38-NP-Benefits, NP-Costs and NPV: T.Scenario 1, Discount rate 7%

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	VPN (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	3085.4	0.0	0.0	0.0	0.0	0.0	950.8	0.0	0.0	0.0	0.0	0.0	0.0	-2134.5
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	2375.0	3425.1	93.6	724.7	151.4	57.5	479.6	1055.5	2024.7	486.7	285.8	338.5	75.0	25.2	-81.1
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	499.1	0.0	0.0	0.0	0.0	0.0	153.8	0.0	0.0	0.0	0.0	0.0	0.0	-345.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	554.6	12.3	137.7	26.3	10.1	84.1	170.9	352.0	84.6	49.7	128.0	18.7	5.2	185.8
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	554.6	24.1	137.7	26.3	10.1	84.1	170.9	419.8	104.8	63.4	128.0	18.7	5.2	-0.7
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1011.5	39.6	137.7	49.7	10.1	84.1	170.9	352.0	84.6	49.7	128.0	18.7	5.2	-913.4
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1011.5	51.4	240.5	49.7	10.1	84.1	170.9	419.8	104.8	63.4	128.0	18.7	5.2	-997.1
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1235.9	55.2	137.7	49.7	10.1	84.1	170.9	419.8	104.8	63.4	128.0	18.7	5.2	-1416.5
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1235.9	60.9	240.5	49.7	10.1	84.1	170.9	419.8	104.8	63.4	128.0	18.7	5.2	-1452.0
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1235.9	60.9	240.5	49.7	10.1	84.1	170.9	419.8	104.8	63.4	128.0	18.7	5.2	-1452.0

Table 39- %Benefits and %Costs: T.Scenario 1, Discount rate 7%

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+C	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	950.8	0%	0%	0%	0%	100%	0%	0%	0%	3085.4	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-81.1	5798.2	35%	6%	10%	5%	18%	8%	4%	14%	5800.1	41%	59%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	153.8	0%	0%	0%	0%	100%	0%	0%	0%	499.1	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	185.8	1079.8	33%	12%	10%	5%	16%	8%	3%	14%	866.6	36%	64%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	-0.7	1193.3	35%	11%	10%	6%	14%	7%	3%	14%	1166.6	52%	48%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-913.4	1130.5	31%	11%	9%	5%	15%	7%	5%	16%	2016.5	50%	50%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-997.1	1346.8	31%	10%	9%	5%	13%	6%	4%	22%	2316.5	56%	44%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1416.5	1247.8	34%	10%	10%	5%	14%	7%	5%	15%	2636.9	53%	47%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1452.0	1356.3	31%	9%	9%	5%	13%	6%	4%	22%	2780.9	56%	44%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1452.0	1356.3	31%	9%	9%	5%	13%	6%	4%	22%	2780.9	56%	44%

Table 40- BCA Summary: T.Scenario 1, Discount rate 7%

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario)	Passengers Volume: Peak Hour & P.Direction	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-81.1	1.00	2053.4	0.0	0.0	2638	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	0.31		0.0		2960	2600	1.14
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	185.8	1.25	531.1	-93.6	0.0	3289	3520	0.93
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	-0.7	1.02	344.6	-183.6	0.0	3289	5500	0.60
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-913.4	0.56	-568.1	-301.5	0.0	3289	2800	1.17
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-997.1	0.58	-651.8	-391.5	0.0	3289	8750	0.38
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1416.5	0.47	-1071.2	-420.3	0.0	3289	4032	0.82
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1452.0	0.49	-1106.7	-463.5	0.0	3289	8100	0.41
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1452.0	0.49	-1106.7	-463.5	0.0	3289	21600	0.15

Table 41-NP-Benefits, NP-Costs and NPV: T.Scenario 1, Discount rate 4%

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	1833.0	0.0	0.0	0.0	0.0	0.0	564.9	0.0	0.0	0.0	0.0	0.0	0.0	-1268.1
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1011.9	2035.4	93.6	437.3	89.9	34.2	285.7	627.3	1203.2	289.2	169.9	213.4	45.9	15.2	408.0
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	499.1	0.0	0.0	0.0	0.0	0.0	153.8	0.0	0.0	0.0	0.0	0.0	0.0	-345.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	554.6	12.3	190.8	36.5	14.0	116.5	170.9	487.7	117.2	68.8	188.1	26.6	7.2	530.1
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	554.6	24.1	190.8	36.5	14.0	116.5	170.9	581.6	145.2	87.8	188.1	26.6	7.2	382.8
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1011.5	39.6	190.8	68.9	14.0	116.5	170.9	487.7	117.2	68.8	188.1	26.6	7.2	-560.1
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1011.5	51.4	333.2	68.9	14.0	116.5	170.9	581.6	145.2	87.8	188.1	26.6	7.2	-565.0
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1235.9	55.2	190.8	68.9	14.0	116.5	170.9	581.6	145.2	87.8	188.1	26.6	7.2	-1024.0
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1235.9	60.9	333.2	68.9	14.0	116.5	170.9	581.6	145.2	87.8	188.1	26.6	7.2	-1019.9
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1235.9	60.9	333.2	68.9	14.0	116.5	170.9	581.6	145.2	87.8	188.1	26.6	7.2	-1019.9

Table 42- %Benefits and %Costs: T.Scenario 1, Discount rate 4%

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	564.9	0%	0%	0%	0%	100%	0%	0%	0%	1833.0	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	408.0	3504.8	34%	6%	10%	5%	18%	8%	4%	15%	3047.3	33%	67%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	153.8	0%	0%	0%	0%	100%	0%	0%	0%	499.1	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	530.1	1436.7	34%	13%	10%	5%	12%	8%	4%	14%	866.6	36%	64%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	382.8	1589.4	37%	12%	11%	6%	11%	7%	3%	14%	1166.6	52%	48%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-560.1	1496.5	33%	13%	10%	5%	11%	8%	6%	15%	2016.5	50%	50%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-565.0	1791.5	32%	10%	10%	5%	10%	7%	5%	21%	2316.5	56%	44%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1024.0	1652.9	35%	11%	10%	6%	10%	7%	5%	15%	2636.9	53%	47%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1019.9	1801.0	32%	10%	10%	5%	9%	6%	5%	22%	2780.9	56%	44%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1019.9	1801.0	32%	10%	10%	5%	9%	6%	5%	22%	2780.9	56%	44%

Table 43- BCA Summary: T.Scenario 1, Discount rate 4%

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	408.0	1.15	1676.1	0.0	489.1	2638	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	0.31		0.0		2960	2600	1.14
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	530.1	1.66	875.4	-93.6	344.3	3289	3520	0.93
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	382.8	1.36	728.1	-183.6	383.5	3289	5500	0.60
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-560.1	0.74	-214.8	-301.5	353.3	3289	2800	1.17
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-565.0	0.77	-219.7	-391.5	432.1	3289	8750	0.38
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1024.0	0.63	-678.7	-420.3	392.5	3289	4032	0.82
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1019.9	0.65	-674.6	-463.5	432.1	3289	8100	0.41
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1019.9	0.65	-674.6	-463.5	432.1	3289	21600	0.15

For both analyses (Real discount rate 7% and 4%), benefits distribution remains with no major variation, being the Transit Travel Time savings at the peak hour the most important benefit. Between Cars and Transit Travel time savings, at least 40% of the benefits of a Transit Project are generated only at peak hours.

Transit Modes NPV and BCR improve considerably if a 4% discount rate is considered.

According to this BCA, the Bus Rapid Transit options offer the best NPV and still offer enough capacity for future patronage growth. The Best option, option 3, is exactly the O'Bahn as it is currently in operation (Passengers 2050/Capacity = 0.93).

BCR obtained for Ex-Post are 1.00 (r=7%) and 1.15 (r=4%).

If Environmental Costs and Option & Non-Use value are neglected (similar to Past evaluations), the BCR for Ex-Post would be 0.84 (r=7%) and 0.97 (r=4%). These values are very close to past evaluation, which predicted a BCR between 0.70 and 1.00.

In addition, other combinations are calculated to measure sensitivity:

Table 44-NP-Benefits, NP-Costs and NPV: T.Scenario 1, Discount rate 7%, High VOT peak

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	3085.4	0.0	0.0	0.0	0.0	0.0	950.8	0.0	0.0	0.0	0.0	0.0	0.0	-2134.5
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	2375.0	3425.1	93.6	724.7	151.4	57.5	479.6	1055.5	2880.1	486.7	285.8	481.6	75.0	25.2	891.5
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	499.1	0.0	0.0	0.0	0.0	0.0	153.8	0.0	0.0	0.0	0.0	0.0	0.0	-345.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	554.6	12.3	137.7	26.3	10.1	84.1	170.9	500.8	84.6	49.7	182.1	18.7	5.2	378.9
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	554.6	24.1	137.7	26.3	10.1	84.1	170.9	597.2	104.8	63.4	182.1	18.7	5.2	221.0
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1011.5	39.6	137.7	49.7	10.1	84.1	170.9	500.8	84.6	49.7	182.1	18.7	5.2	-720.3
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1011.5	51.4	240.5	49.7	10.1	84.1	170.9	597.2	104.8	63.4	182.1	18.7	5.2	-775.4
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1235.9	55.2	137.7	49.7	10.1	84.1	170.9	597.2	104.8	63.4	182.1	18.7	5.2	-1194.8
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1235.9	60.9	240.5	49.7	10.1	84.1	170.9	597.2	104.8	63.4	182.1	18.7	5.2	-1230.3
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1235.9	60.9	240.5	49.7	10.1	84.1	170.9	597.2	104.8	63.4	182.1	18.7	5.2	-1230.3

Table 45- %Benefits and %Costs: T.Scenario 1, Discount rate 7%, High VOT peak

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	950.8	0%	0%	0%	0%	100%	0%	0%	0%	3085.4	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	891.5	6796.6	42%	7%	8%	5%	16%	7%	3%	12%	5800.1	41%	59%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	153.8	0%	0%	0%	0%	100%	0%	0%	0%	499.1	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	378.9	1282.6	39%	14%	8%	4%	13%	7%	3%	12%	866.6	36%	64%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	221.0	1424.7	42%	13%	9%	5%	12%	6%	3%	11%	1166.6	52%	48%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-720.3	1333.3	38%	14%	8%	4%	13%	6%	4%	13%	2016.5	50%	50%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-775.4	1578.3	38%	12%	8%	4%	11%	5%	4%	18%	2316.5	56%	44%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1194.8	1479.3	40%	12%	8%	5%	12%	6%	4%	13%	2636.9	53%	47%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1230.3	1587.7	38%	11%	8%	4%	11%	5%	4%	19%	2780.9	56%	44%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1230.3	1587.7	38%	11%	8%	4%	11%	5%	4%	19%	2780.9	56%	44%

Table 46- BCA Summary: T.Scenario 1, Discount rate 7%, High VOT peak

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	891.5	1.17	3026.0	0.0	972.6	2638	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	0.31		0.0		2960	2600	1.14
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	378.9	1.48	724.2	-93.6	193.1	3289	3520	0.93
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	221.0	1.22	566.3	-183.6	221.7	3289	5500	0.60
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-720.3	0.66	-375.0	-301.5	193.1	3289	2800	1.17
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-775.4	0.68	-430.1	-391.5	221.7	3289	8750	0.38
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1194.8	0.56	-849.5	-420.3	221.7	3289	4032	0.82
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1230.3	0.57	-885.0	-463.5	221.7	3289	8100	0.41
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1230.3	0.57	-885.0	-463.5	221.7	3289	21600	0.15

When High VOT is considered at peak hours, the NPV, BCR and Importance of Benefits at Peak hours is improved for all options.

However, a discount rate of 4% generates better results than considering high VOT at peak hours.

Table 47-NP-Benefits, NP-Costs and NPV: T.Scenario 1, Discount rate 4%, High VOT peak

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	1833.0	0.0	0.0	0.0	0.0	0.0	564.9	0.0	0.0	0.0	0.0	0.0	0.0	-1268.1
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1011.9	2035.4	93.6	437.3	89.9	34.2	285.7	627.3	1711.5	289.2	169.9	303.5	45.9	15.2	990.2
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	499.1	0.0	0.0	0.0	0.0	0.0	153.8	0.0	0.0	0.0	0.0	0.0	0.0	-345.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	554.6	12.3	190.8	36.5	14.0	116.5	170.9	693.7	117.2	68.8	267.6	26.6	7.2	801.3
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	554.6	24.1	190.8	36.5	14.0	116.5	170.9	827.3	145.2	87.8	267.6	26.6	7.2	693.7
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1011.5	39.6	190.8	68.9	14.0	116.5	170.9	693.7	117.2	68.8	267.6	26.6	7.2	-288.9
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1011.5	51.4	333.2	68.9	14.0	116.5	170.9	827.3	145.2	87.8	267.6	26.6	7.2	-254.1
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1235.9	55.2	190.8	68.9	14.0	116.5	170.9	827.3	145.2	87.8	267.6	26.6	7.2	-713.1
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1235.9	60.9	333.2	68.9	14.0	116.5	170.9	827.3	145.2	87.8	267.6	26.6	7.2	-709.1
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1235.9	60.9	333.2	68.9	14.0	116.5	170.9	827.3	145.2	87.8	267.6	26.6	7.2	-709.1

Table 48- %Benefits and %Costs: T.Scenario 1, Discount rate 4%, High VOT peak

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	564.9	0%	0%	0%	0%	100%	0%	0%	0%	1833.0	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	990.2	4103.3	42%	7%	8%	5%	15%	7%	3%	13%	3047.3	33%	67%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	153.8	0%	0%	0%	0%	100%	0%	0%	0%	499.1	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	801.3	1722.2	40%	16%	8%	4%	10%	7%	3%	12%	866.6	36%	64%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	693.7	1914.6	43%	14%	9%	5%	9%	6%	3%	11%	1166.6	52%	48%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-288.9	1782.0	39%	15%	8%	4%	10%	7%	5%	13%	2016.5	50%	50%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-254.1	2116.7	39%	13%	8%	4%	8%	6%	4%	18%	2316.5	56%	44%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-713.1	1978.1	42%	14%	9%	5%	9%	6%	4%	12%	2636.9	53%	47%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-709.1	2126.2	39%	13%	8%	4%	8%	5%	4%	19%	2780.9	56%	44%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-709.1	2126.2	39%	13%	8%	4%	8%	5%	4%	19%	2780.9	56%	44%

Table 49- BCA Summary: T.Scenario 1, Discount rate 4%, High VOT peak

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	990.2	1.35	2258.3	0.0	1071.3	2638	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-345.3	0.31		0.0		2960	2600	1.14
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	801.3	1.99	1146.6	-93.6	615.5	3289	3520	0.93
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	693.7	1.64	1039.0	-183.6	694.4	3289	5500	0.60
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-288.9	0.88	56.4	-301.5	624.5	3289	2800	1.17
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-254.1	0.91	91.2	-391.5	743.0	3289	8750	0.38
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-713.1	0.75	-367.8	-420.3	703.4	3289	4032	0.82
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-709.1	0.76	-363.7	-463.5	743.0	3289	8100	0.41
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-709.1	0.76	-363.7	-463.5	743.0	3289	21600	0.15

A discount rate of 4% and High VOT at peak hours are optimistic considerations, yet still reasonable. With this consideration, NPB and BCR are the highest for T.Scenario 1. Similarly, Bus Rapid Transit options are still the best. However, only under these optimistic considerations, Light Rail Options offer better NPV than Do nothing. In particular, Light Rail Transit 2 (improved performance) could be a feasible option. Nevertheless, BRT options offer much better NPV and BCR.

8.2. T.Scenario 2

Table 50-NP-Benefits, NP-Costs and NPV: T.Scenario 2, Discount rate 7%

Evaluation	Period	Alternatives		Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	3085.4	0.0	0.0	0.0	0.0	0.0	950.8	0.0	0.0	0.0	0.0	0.0	0.0	-2134.5
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	2375.0	3425.1	93.6	724.7	151.4	57.5	479.6	1055.5	2024.7	486.7	285.8	338.5	75.0	25.2	-81.1
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	522.3	0.0	0.0	0.0	0.0	0.0	161.0	0.0	0.0	0.0	0.0	0.0	0.0	-361.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	580.3	12.3	137.7	27.5	10.5	87.8	178.8	367.3	88.3	51.8	167.3	21.6	5.6	229.1
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	580.3	24.1	137.7	27.5	10.5	87.8	178.8	438.0	109.4	66.1	167.3	21.6	5.6	47.0
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1058.5	39.6	137.7	51.9	10.5	87.8	178.8	367.3	88.3	51.8	167.3	21.6	5.6	-890.3
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1058.5	51.4	240.5	51.9	10.5	87.8	178.8	438.0	109.4	66.1	167.3	21.6	5.6	-969.6
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1293.3	55.2	137.7	51.9	10.5	87.8	178.8	438.0	109.4	66.1	167.3	21.6	5.6	-1399.4
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1293.3	60.9	240.5	51.9	10.5	87.8	178.8	438.0	109.4	66.1	167.3	21.6	5.6	-1434.9
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1293.3	60.9	240.5	51.9	10.5	87.8	178.8	438.0	109.4	66.1	167.3	21.6	5.6	-1434.9

Table 51- %Benefits and %Costs: T.Scenario 2, Discount rate 7%

					Benefits Distribution									Costs Distribution		
Evaluation	Period	Alternatives		NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	950.8	0%	0%	0%	0%	100%	0%	0%	0%	3085.4	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-81.1	5798.1	35%	6%	10%	5%	18%	8%	4%	14%	5800.1	41%	59%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	161.0	0%	0%	0%	0%	100%	0%	0%	0%	522.3	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	229.1	1156.5	32%	14%	10%	5%	15%	8%	3%	13%	892.3	35%	65%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	47.0	1274.4	34%	13%	10%	6%	14%	7%	3%	13%	1192.3	51%	49%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-890.3	1208.3	30%	14%	9%	5%	15%	7%	5%	15%	2063.5	49%	51%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-969.6	1429.0	31%	12%	9%	5%	13%	6%	4%	20%	2363.5	55%	45%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1399.4	1329.9	33%	13%	10%	5%	13%	7%	5%	15%	2694.3	52%	48%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1434.9	1438.4	30%	12%	9%	5%	12%	6%	4%	21%	2838.3	54%	46%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1434.9	1438.4	30%	12%	9%	5%	12%	6%	4%	21%	2838.3	54%	46%

Table 52- BCA Summary: T.Scenario 2, Discount rate 7%

Evaluation	Period	Alternatives		NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	0.31		0.0		2373	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-81.1	1.00	2053.4	0.0	0.0	2637	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	0.31		0.0		3395	2600	1.31
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	229.1	1.30	590.5	-93.6	43.3	3772	3520	1.07
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	47.0	1.07	408.4	-183.6	47.7	3772	5500	0.69
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-890.3	0.59	-528.9	-301.5	23.1	3772	2800	1.35
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-969.6	0.60	-608.3	-391.5	27.5	3772	8750	0.43
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1399.4	0.49	-1038.1	-420.3	17.1	3772	4032	0.94
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1434.9	0.51	-1073.6	-463.5	17.1	3772	8100	0.47
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1434.9	0.51	-1073.6	-463.5	17.1	3772	21600	0.17

Table 53-NP-Benefits, NP-Costs and NPV: T.Scenario 2, Discount rate 4%

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	1833.0	0.0	0.0	0.0	0.0	0.0	564.9	0.0	0.0	0.0	0.0	0.0	0.0	-1268.1
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1011.9	2035.4	93.6	437.3	89.9	34.2	285.7	627.3	1203.2	289.2	169.9	213.4	45.9	15.2	408.0
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	522.3	0.0	0.0	0.0	0.0	0.0	161.0	0.0	0.0	0.0	0.0	0.0	0.0	-361.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	580.3	12.3	190.8	38.4	14.7	122.7	178.8	513.4	123.4	72.5	259.1	31.7	8.0	619.5
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	580.3	24.1	190.8	38.4	14.7	122.7	178.8	612.2	152.9	92.4	259.1	31.7	8.0	479.6
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1058.5	39.6	190.8	72.5	14.7	122.7	178.8	513.4	123.4	72.5	259.1	31.7	8.0	-490.2
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1058.5	51.4	333.2	72.5	14.7	122.7	178.8	612.2	152.9	92.4	259.1	31.7	8.0	-487.7
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1293.3	55.2	190.8	72.5	14.7	122.7	178.8	612.2	152.9	92.4	259.1	31.7	8.0	-957.1
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1293.3	60.9	333.2	72.5	14.7	122.7	178.8	612.2	152.9	92.4	259.1	31.7	8.0	-953.0
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1293.3	60.9	333.2	72.5	14.7	122.7	178.8	612.2	152.9	92.4	259.1	31.7	8.0	-953.0

Table 54- %Benefits and %Costs: T.Scenario 2, Discount rate 4%

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	564.9	0%	0%	0%	0%	100%	0%	0%	0%	1833.0	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	408.0	3504.8	34%	6%	10%	5%	18%	8%	4%	15%	3047.3	33%	67%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	161.0	0%	0%	0%	0%	100%	0%	0%	0%	522.3	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	619.5	1565.8	33%	17%	10%	5%	11%	8%	3%	13%	892.3	35%	65%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	479.6	1725.8	35%	15%	11%	6%	10%	7%	3%	12%	1192.3	51%	49%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-490.2	1627.2	32%	16%	10%	5%	11%	8%	5%	14%	2063.5	49%	51%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-487.7	1929.7	32%	13%	10%	5%	9%	6%	5%	20%	2363.5	55%	45%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-957.1	1791.1	34%	14%	10%	6%	10%	7%	5%	14%	2694.3	52%	48%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-953.0	1939.1	32%	13%	10%	5%	9%	6%	4%	20%	2838.3	54%	46%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-953.0	1939.1	32%	13%	10%	5%	9%	6%	4%	20%	2838.3	54%	46%

Table 55- BCA Summary: T.Scenario 2, Discount rate 4%

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	0.31		0.0		2373	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	408.0	1.15	1676.1	0.0	489.1	2637	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	0.31		0.0		3395	2600	1.31
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	619.5	1.75	980.9	-93.6	433.7	3772	3520	1.07
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	479.6	1.45	841.0	-183.6	480.3	3772	5500	0.69
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-490.2	0.79	-128.8	-301.5	423.2	3772	2800	1.35
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-487.7	0.82	-126.3	-391.5	509.4	3772	8750	0.43
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-957.1	0.66	-595.8	-420.3	459.4	3772	4032	0.94
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-953.0	0.68	-591.7	-463.5	499.0	3772	8100	0.47
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-953.0	0.68	-591.7	-463.5	499.0	3772	21600	0.17

Table 56-NP-Benefits, NP-Costs and NPV: T.Scenario 2, Discount rate 4% and High VOT

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	1833.0	0.0	0.0	0.0	0.0	0.0	564.9	0.0	0.0	0.0	0.0	0.0	0.0	-1268.1
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1011.9	2035.4	93.6	437.3	89.9	34.2	285.7	627.3	1711.5	289.2	169.9	303.5	45.9	15.2	990.2
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	522.3	0.0	0.0	0.0	0.0	0.0	161.0	0.0	0.0	0.0	0.0	0.0	0.0	-361.3
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	580.3	12.3	190.8	38.4	14.7	122.7	178.8	730.2	123.4	72.5	368.5	31.7	8.0	926.1
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	580.3	24.1	190.8	38.4	14.7	122.7	178.8	870.9	152.9	92.4	368.5	31.7	8.0	828.0
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1058.5	39.6	190.8	72.5	14.7	122.7	178.8	730.2	123.4	72.5	368.5	31.7	8.0	-183.6
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1058.5	51.4	333.2	72.5	14.7	122.7	178.8	870.9	152.9	92.4	368.5	31.7	8.0	-139.3
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1293.3	55.2	190.8	72.5	14.7	122.7	178.8	870.9	152.9	92.4	368.5	31.7	8.0	-608.7
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1293.3	60.9	333.2	72.5	14.7	122.7	178.8	870.9	152.9	92.4	368.5	31.7	8.0	-604.7
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1293.3	60.9	333.2	72.5	14.7	122.7	178.8	870.9	152.9	92.4	368.5	31.7	8.0	-604.7

Table 57- %Benefits and %Costs: T.Scenario 2, Discount rate 4% and High VOT

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	564.9	0%	0%	0%	0%	100%	0%	0%	0%	1833.0	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	990.2	4103.3	42%	7%	8%	5%	15%	7%	3%	13%	3047.3	33%	67%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	161.0	0%	0%	0%	0%	100%	0%	0%	0%	522.3	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	926.1	1892.1	39%	19%	8%	4%	9%	6%	3%	11%	892.3	35%	65%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	828.0	2093.9	42%	18%	9%	5%	9%	6%	3%	10%	1192.3	51%	49%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-183.6	1953.5	37%	19%	8%	4%	9%	6%	4%	12%	2063.5	49%	51%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-139.3	2297.8	38%	16%	8%	4%	8%	5%	4%	17%	2363.5	55%	45%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-608.7	2159.2	40%	17%	9%	5%	8%	6%	4%	11%	2694.3	52%	48%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-604.7	2307.2	38%	16%	8%	4%	8%	5%	4%	17%	2838.3	54%	46%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-604.7	2307.2	38%	16%	8%	4%	8%	5%	4%	17%	2838.3	54%	46%

Table 58- BCA Summary: T.Scenario 2, Discount rate 4% and High VOT

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	0.31		0.0		2373	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	990.2	1.35	2258.3	0.0	1071.3	2637	3520	0.75
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-361.3	0.31		0.0		3395	2600	1.31
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	926.1	2.12	1287.5	-93.6	740.3	3772	3520	1.07
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	828.0	1.76	1189.3	-183.6	828.7	3772	5500	0.69
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-183.6	0.95	177.8	-301.5	729.8	3772	2800	1.35
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-139.3	0.97	222.0	-391.5	857.8	3772	8750	0.43
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-608.7	0.80	-247.4	-420.3	807.8	3772	4032	0.94
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-604.7	0.81	-243.3	-463.5	847.4	3772	8100	0.47
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-604.7	0.81	-243.3	-463.5	847.4	3772	21600	0.17

Considering the T.Scenario 2, which is a likely future scenario, results are very similar to T.Scenario 1. However, the option with the best NPV and BCR, and which can still offer sufficient capacity for future demand, is now Option 4, BRT2 with improved performance. This option produces a positive NPV with all considerations.

Regarding Light Rail options, similar to T.Scenario 1, they offer better NPV than the Base Case only with the optimistic considerations (r=4% and High VOT at peak hours).

In Short, Bus Rapid Transit options offer the best economic performance, with positive NPV. However, performance improvement (to improve Capacity) may be required (e.g. if the demand increases like T.Scenario 2).

On the other hand, Light Rail Options could be good options (better than the Base Case, but still negative NPV) under optimistic considerations.

Rail Options are not suitable for the present and forecast conditions (at least T.Scenario 1 and 2). Demand is relatively low for a Heavy Rail Transit project.

8.3. T.Scenario 3

This is Scenario is analysed for sensitivity. The aim of this scenario is to evaluate results with high increment in the transit demand.

Table 59-NP-Benefits, NP-Costs and NPV: T.Scenario 3, Discount rate 7%

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	3085.4	0.0	0.0	0.0	0.0	0.0	950.8	0.0	0.0	0.0	0.0	0.0	0.0	-2134.5
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	2375.0	3429.2	93.6	724.7	151.5	58.3	486.5	1056.8	2027.1	487.3	286.2	343.9	76.1	25.5	-67.1
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	573.2	0.0	0.0	0.0	0.0	0.0	176.6	0.0	0.0	0.0	0.0	0.0	0.0	-396.5
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	700.5	12.3	137.7	33.0	25.2	210.7	215.9	440.7	106.0	62.2	525.4	64.0	14.0	725.7
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	700.5	24.1	137.7	33.0	25.2	210.7	215.9	525.6	131.2	79.4	525.4	64.0	14.0	564.8
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1277.7	39.6	137.7	62.3	25.2	210.7	215.9	440.7	106.0	62.2	525.4	64.0	14.0	-487.8
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1277.7	51.4	240.5	62.3	25.2	210.7	215.9	525.6	131.2	79.4	525.4	64.0	14.0	-545.9
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1561.2	55.2	137.7	62.3	25.2	210.7	215.9	525.6	131.2	79.4	525.4	64.0	14.0	-1024.4
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1561.2	60.9	240.5	62.3	25.2	210.7	215.9	525.6	131.2	79.4	525.4	64.0	14.0	-1059.9
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1561.2	60.9	240.5	62.3	25.2	210.7	215.9	525.6	131.2	79.4	525.4	64.0	14.0	-1059.9

Table 60- %Benefits and %Costs: T.Scenario 3, Discount rate 7%

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	950.8	0%	0%	0%	0%	100%	0%	0%	0%	3085.4	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-67.1	5817.5	35%	6%	10%	5%	18%	8%	4%	14%	5804.2	41%	59%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-396.5	176.6	0%	0%	0%	0%	100%	0%	0%	0%	573.2	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	725.7	1847.1	24%	28%	9%	4%	12%	11%	3%	8%	1012.5	31%	69%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	564.8	1986.2	26%	26%	10%	5%	11%	11%	3%	8%	1312.5	47%	53%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-487.8	1903.7	23%	28%	9%	4%	11%	11%	5%	9%	2282.7	44%	56%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-545.9	2145.6	24%	24%	9%	4%	10%	10%	4%	14%	2582.7	51%	49%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1024.4	2046.6	26%	26%	10%	5%	11%	10%	4%	9%	2962.2	47%	53%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1059.9	2155.1	24%	24%	9%	4%	10%	10%	4%	14%	3106.2	50%	50%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1059.9	2155.1	24%	24%	9%	4%	10%	10%	4%	14%	3106.2	50%	50%

Table 61- BCA Summary: T.Scenario 3, Discount rate 7%

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-2134.5	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	-67.1	1.00	2067.5	0.0	14.0	2902	3520	0.82
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-396.5	0.31		0.0		4300	2600	1.65
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	725.7	1.82	1122.3	-93.6	539.9	5256	3520	1.49
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	564.8	1.51	961.4	-183.6	565.5	5256	5500	0.96
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	-487.8	0.83	-91.3	-301.5	425.6	5256	2800	1.88
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	-545.9	0.83	-149.4	-391.5	451.2	5256	8750	0.60
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	-1024.4	0.69	-627.8	-420.3	392.1	5256	4032	1.30
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	-1059.9	0.69	-663.4	-463.5	392.1	5256	8100	0.65
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	-1059.9	0.69	-663.4	-463.5	392.1	5256	21600	0.24

Table 62-NP-Benefits, NP-Costs and NPV: T.Scenario 3, Discount rate 4% and High VOT

Evaluation	Period		Alternatives	Project Capital Cost [$ M]	Transit Operation Costs [M $]	Project Residual Value [$ M]	Option Value Benefits [M $]	Transit Enviornmental Costs Reduction [M $]	Car Enviornmental Costs Reduction [M $]	Car Operation Savings [M $]	Fare Revenue [M $]	TTTp-Savings [M $]	TTTip-Savings [M $]	TTTop-Savings [M $]	CTTp-Savings [M $]	CTTip-Savings [M $]	CTTop-Savings [M $]	NPV (B-C) [M $]
				(C)	(C)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	(B)	
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.0	1833.0	0.0	0.0	0.0	0.0	0.0	564.9	0.0	0.0	0.0	0.0	0.0	0.0	-1268.1
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1011.9	2039.5	93.6	437.3	90.1	35.1	292.6	628.5	1714.9	289.8	170.2	311.2	47.0	15.5	1007.1
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.0	573.2	0.0	0.0	0.0	0.0	0.0	176.6	0.0	0.0	0.0	0.0	0.0	0.0	-396.5
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	312.0	700.5	12.3	190.8	46.8	35.9	299.4	215.9	891.1	150.6	88.4	1245.4	103.0	21.1	2041.3
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	612.0	700.5	24.1	190.8	46.8	35.9	299.4	215.9	1062.8	186.5	112.8	1245.4	103.0	21.1	1985.0
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	1005.0	1277.7	39.6	190.8	88.5	35.9	299.4	215.9	891.1	150.6	88.4	1245.4	103.0	21.1	840.1
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	1305.0	1277.7	51.4	333.2	88.5	35.9	299.4	215.9	1062.8	186.5	112.8	1245.4	103.0	21.1	926.2
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	1401.0	1561.2	55.2	190.8	88.5	35.9	299.4	215.9	1062.8	186.5	112.8	1245.4	103.0	21.1	408.1
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	1545.0	1561.2	60.9	333.2	88.5	35.9	299.4	215.9	1062.8	186.5	112.8	1245.4	103.0	21.1	412.2
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	1545.0	1561.2	60.9	333.2	88.5	35.9	299.4	215.9	1062.8	186.5	112.8	1245.4	103.0	21.1	412.2

Table 63- %Benefits and %Costs: T.Scenario 3, Discount rate 4% and High VOT

					Benefits Distribution									Costs Distribution		
Evaluation	Period		Alternatives	NPV (B-C) [M $]	Total Benefits [M $]	TT savings at Peak: Transit	TT savings at Peak: Cars	TT savings at Inter Peak: Transit+Cars	TT savings at Off Peak: Transit+Cars	Fare Revenue	Car Operational Savings	Environmental Costs Reduction (Car and Transit)	Residual Value and Option Value	Total Costs [M $]	Project Capital Cost	Transit Operation Costs
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	564.9	0%	0%	0%	0%	100%	0%	0%	0%	1833.0	0%	100%
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1007.1	4126.0	42%	8%	8%	5%	15%	7%	3%	13%	3051.4	33%	67%
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-396.5	176.6	0%	0%	0%	0%	100%	0%	0%	0%	573.2	0%	100%
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	2041.3	3300.8	27%	38%	8%	3%	7%	9%	3%	6%	1012.5	31%	69%
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	1985.0	3544.5	30%	35%	8%	4%	6%	8%	2%	6%	1312.5	47%	53%
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	840.1	3369.7	26%	37%	8%	3%	6%	9%	4%	7%	2282.7	44%	56%
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	926.2	3755.9	28%	33%	8%	4%	6%	8%	3%	10%	2582.7	51%	49%
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	408.1	3617.2	29%	34%	8%	4%	6%	8%	3%	7%	2962.2	47%	53%
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	412.2	3765.3	28%	33%	8%	4%	6%	8%	3%	10%	3106.2	50%	50%
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	412.2	3765.3	28%	33%	8%	4%	6%	8%	3%	10%	3106.2	50%	50%

Table 64- BCA Summary: T.Scenario 3, Discount rate 4% and High VOT

Evaluation	Period		Alternatives	NPV (B-C) [M $]	B/C Ratio	Comparison with Do Nothing [M $]	Capital Cost Risks (30%) [M $]	Sensitivity (Compared with Base Evaluation Scenario) [M $]	Passengers Volume: Peak Hour & P.Direction [p/h]	Transit Capacity [sps/h]	Passengers / Capacity
Ex-Post	1990-2020	0	Do nothing (Base Case)	-1268.1	0.31		0.0		2374	2600	0.91
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1007.1	1.35	2275.3	0.0	1088.2	2902	3520	0.82
Ex-Ante	2020-2050	2	Do nothing (Base Case)	-396.5	0.31		0.0		4300	2600	1.65
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	2041.3	3.26	2437.8	-93.6	1855.5	5256	3520	1.49
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	1985.0	2.70	2381.5	-183.6	1985.7	5256	5500	0.96
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	840.1	1.48	1236.6	-301.5	1753.5	5256	2800	1.88
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	926.2	1.45	1322.7	-391.5	1923.3	5256	8750	0.60
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	408.1	1.22	804.7	-420.3	1824.6	5256	4032	1.30
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	412.2	1.21	808.7	-463.5	1864.2	5256	8100	0.65
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	412.2	1.21	808.7	-463.5	1864.2	5256	21600	0.24

When considering the T.Scenario 3, only improved performance options offer sufficient capacity for future demand.

Likewise, the option with the best NPV and BCR is option 4, BRT2 improved performance.

Rail options offer good NPV (even positive) and good BCR, only under optimistic considerations.

Moreover, it is noticed that, with increased demand (both in transit and arterial roads), the benefits produced, which were concentrated in Travel Times Savings at peak hour, are increased even further. Growing from around 40% of the benefits for T.Scenario 1 to 50%-60% for T.Scenario 2.

8.4. Sensitivity Analysis

The following table presents a summary of BCR for all the evaluation conditions considered:

Table 65- Summary of BCR for all Evaluations conditions

Evaluation	Period		Alternatives	Tr.Sc.1 ; r=7%	Tr.Sc.1 ; r=4%	Tr.Sc.1 ; r=7% ; High IVT Value	Tr.Sc.1 ; r=4% ; High IVT Value	Tr.Sc.2 ; r=7%	Tr.Sc.2 ; r=4%	Tr.Sc.2 ; r=4% ; High IVT Value	Tr.Sc.3 ; r=7%	Tr.Sc.3 ; r=4% ; High IVT Value
Ex-Post	1990-2020	0	Do nothing (Base Case)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Ex-Post	1990-2020	1	Bus Rapid Transit (O'Bahn)	1.00	1.15	1.17	1.35	1.00	1.15	1.35	1.00	1.35
Ex-Ante	2020-2050	2	Do nothing (Base Case)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Ex-Ante	2020-2050	3	Bus Rapid Transit (O'Bahn)	1.25	1.66	1.48	1.99	1.30	1.75	2.12	1.82	3.26
Ex-Ante	2020-2050	4	Bus Rapid Transit 2 (O'Bahn)	1.02	1.36	1.22	1.64	1.07	1.45	1.76	1.51	2.70
Ex-Ante	2020-2050	5	Light Rail Rapid Transit	0.56	0.74	0.66	0.88	0.59	0.79	0.95	0.83	1.48
Ex-Ante	2020-2050	6	Light Rail Rapid Transit 2	0.58	0.77	0.68	0.91	0.60	0.82	0.97	0.83	1.45
Ex-Ante	2020-2050	7	Heavy Rail Rapid Transit	0.47	0.63	0.56	0.75	0.49	0.66	0.80	0.69	1.22
Ex-Ante	2020-2050	8	Heavy Rail Rapid Transit Electric	0.49	0.65	0.57	0.76	0.51	0.68	0.81	0.69	1.21
Ex-Ante	2020-2050	9	Heavy Rail Rapid Transit Electric 2	0.49	0.65	0.57	0.76	0.51	0.68	0.81	0.69	1.21

It is noticed that BRT options produce the best BCR for all scenarios, followed by Light Rail and finally Heavy Rail.

It is also noticed that the BCR (and NPV) improves with higher levels of patronage (e.g. from T.Scenario 1 to 2 or 3)

Even if the BCR of all options considered are better than the BCR of the Base Case, the NPV can still be lower than the Base Case, making those cases a worse alternative than Doing Nothing (from the economic/BCA point of view).

Despite option 3 (O'Bahn as it is operating at the present day) offering the best BCR and NPV, it does not offer enough capacity for a potential T.Scenario 2. And even less for an exaggerated T.Scenario 3.

However, option 4 (O'Bahn with improved performance, such as with a Tunnel in the CBD Area) would offer sufficient capacity for a potential T.Scenario 2, and even for the T.Scenario 3. In addition, it offers a positive NPV and BCR above 1 in all evaluation conditions.

Light Rail option 6 (LRT with improved performance) could be a feasible option (at least better than Doing nothing) only under optimistic conditions.

Finally, Heavy Rail options offer acceptable results only with an exaggerated T.Scenario 3 and optimistic considerations. It is deemed that the Modbury corridor does not have sufficient demand to merit Heavy Rail projects.

8.5. Evaluations comparison: Ex-Ante and Ex-Post

In addition, the following table compares the BCR obtained for the O'Bahn evaluations before project implementation and the BCR obtained in this thesis. A summary of the considerations is listed in section 2.7.

Table 65b- BCR comparison of Ex-Ante and Ex-Post evaluations

Evaluation	1974 Dep.Tr. (SA)	1977 Consultant	1979 Dep.Tr. (SA)	1980 Dep.Tr. (SA)	1982 Consultant	1991 Dep.Tr. (SA)	2021 Daniel Pece	2021 Daniel Pece
Int. rate (r)	7%	7%	7%	4%	7%	7%	7%	4%
Transit Mode								
Heavy Rail	0.45	0.34						
Light Rail	0.78	1.00	1.20	0.70				
Busway/guided	1.00	0.70		1.00	0.70	0.77	0.84	0.97

Note: BCR values were calculated with the same criteria as in past evaluations. In other words, Option Value Benefits, Transit Environmental Costs Reduction and Car Environmental Costs Reduction were discarded for this comparison.

Seeing that the BCR is slightly higher than the estimation, means that the project performed slightly better than expected. Moreover, a BCR close to or higher than 1, is considered difficult and rare (which is the case of the O'Bahn if the rest of the benefits are considered like in previous sub-sections). Thus, the O'Bahn can be considered very successful.

8.6. Evaluation framework

Overall, results are based on a macro model, using parameters obtained from ATAP guidelines or special studies that would provide more adequate data. For example, it was observed that Travel Time Savings (Section 5 and 6), Capital costs (Section 3.3), Fare revenue and Operational Costs (Section 2.6 and 7.8) were by far the most important elements in the evaluation. Also, these elements were the ones that required special studies to obtain precise and reliable data.

As a result, the framework created to evaluate this project provides sufficient flexibility to analyse changes in scenarios, sensitivity, future and past periods, etc. The reliability of these results will depend on the quality and accuracy of the data. For example, when the Blue Tooth Travel Time data analysed (Section 6) was discovered to have issues, it was discarded. Then, a different method, Car Travel Time surveys, which is more time consuming, was performed to obtain a high level of accuracy and reliability. In other words, big efforts were dedicated in this thesis to guarantee that the data and the results are of very good quality for defining a solution for a wider engineering issue.

Results and Data can be improved, however, would require much more time and resources just for a slight enhancement (Diminishing Marginal Utility). More detailed studies are only justifiable for Detail/Narrow Engineering issues or design. For instance, when comparing the analyses performed in the past with the analysis performed in this thesis, which was prepared with better data and tools, it is observed similar results. While in the past the BCRs were estimated between 0.7 to 1.0 (in different stages), for this thesis results are estimated consistent and within the same range.

In sum, the results of this thesis provide very good reliability for a wide engineering issue analysis. Further studies would only be worthwhile in the next stage of the design, for a narrow engineering issue analysis (Scoping a transport network problem, Austroads, 2014).

9. Performance Results.

The following graphs show the performance results in a different context, similar to Section 3.4

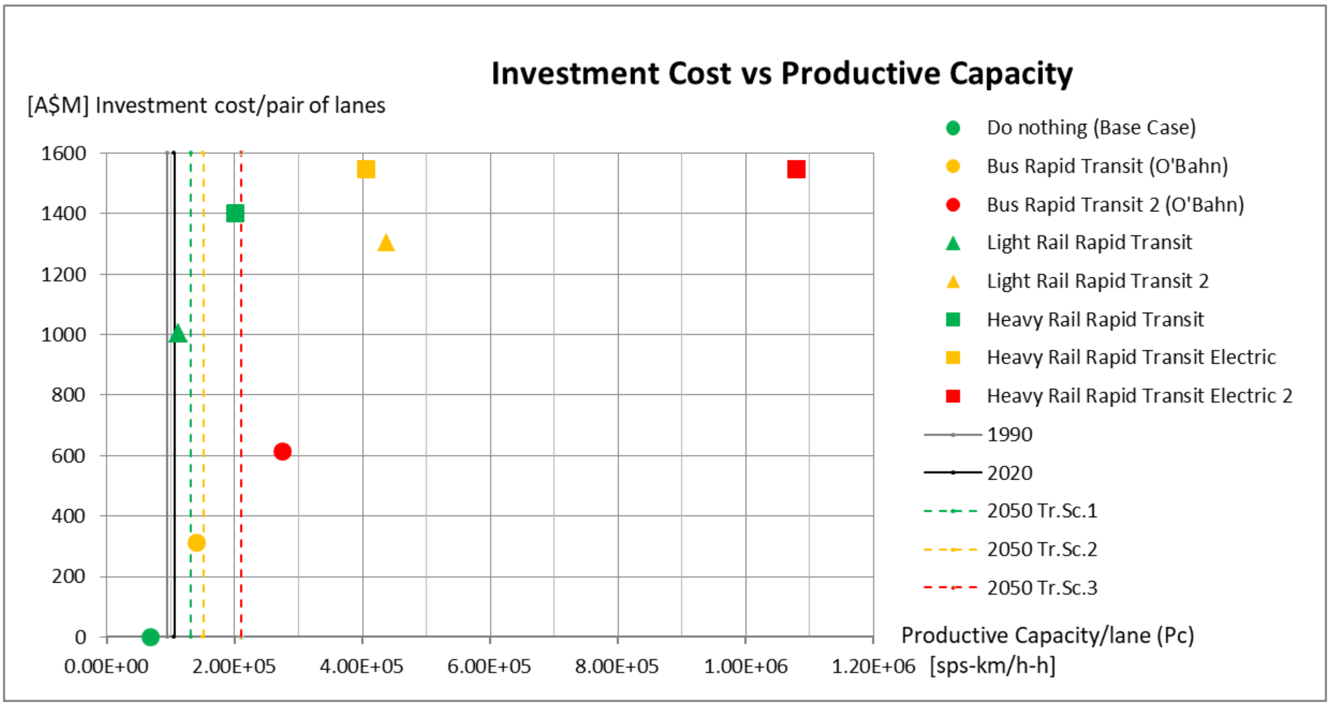

Figure 39-T.Scenarios in Investment Cost vs Productive Capacity

It is observed that both past and future demands sit around Semi-rapid Transit (BRT and LRT which are semi-rapid transit category). Heavy Rail Options offer much higher productive capacity than the required, meaning it is not a cost-effective efficient solution.

This was confirmed in Chapter 8 – BCA Results.

In short, the Modbury corridor requires indeed a semi-rapid transit service. The demand is not suitable to merit a rapid transit service (e.g. with Heavy Rail Modes)

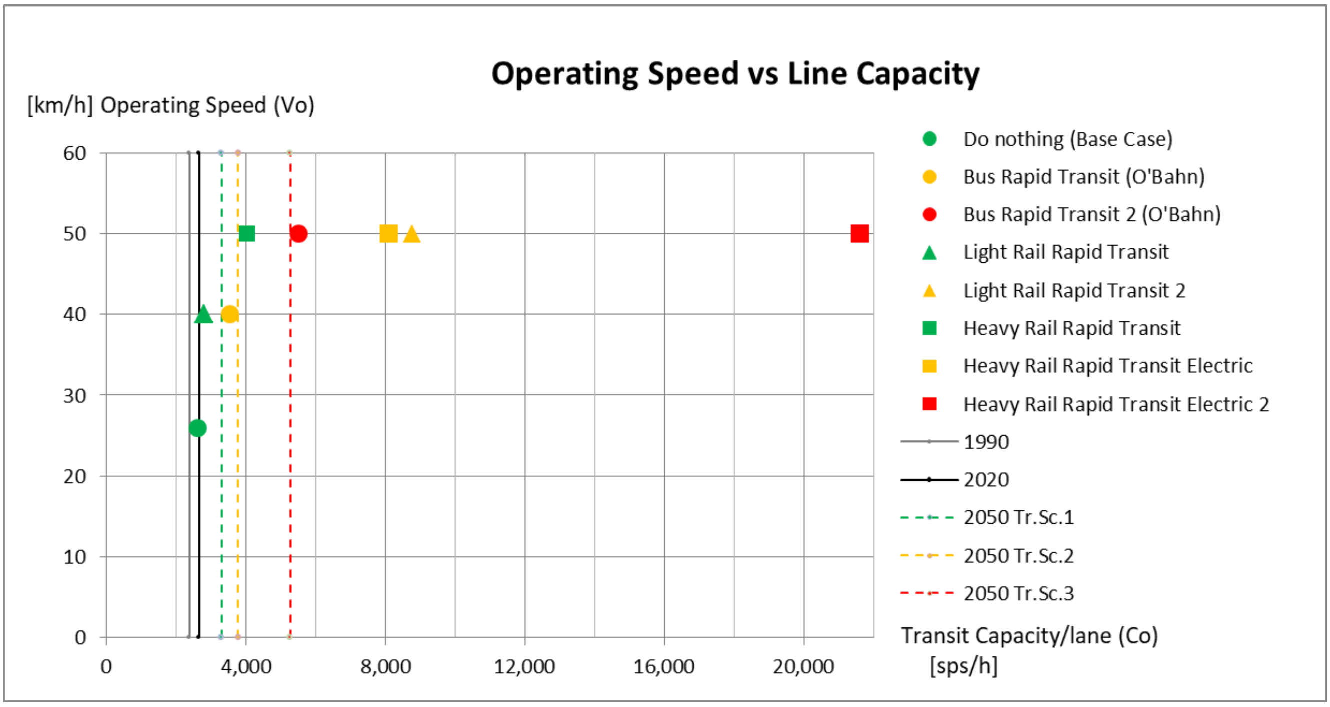

Figure 40-T.Scenarios in Operating speed vs Line Capacity

It is observed in this graph that, even for T.Scenario 3, BRT options are just enough for the Transit demand.

Light Rail Options (somewhere between LRT and LRT2) could offer suitable capacity as well.

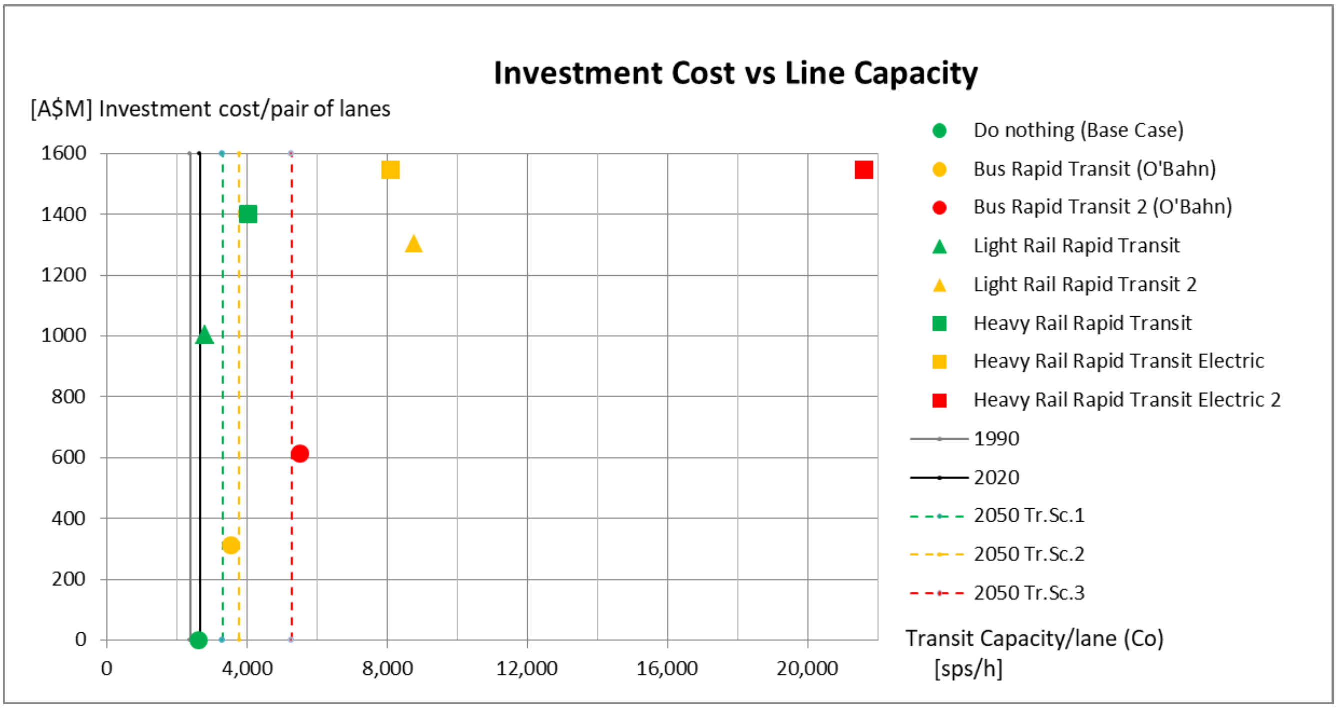

Figure 41-T.Scenarios in Investment Cost vs Line Capacity

Similar to previous graphs, it is noticed that BRT options offer sufficient capacity at the lowest Investment Cost.

If the demand would grow even more than T.Scenario 3, BRT options (at least the ones considered) would not be able to meet the demand, and perhaps Light Rail Options would be more suitable (and likely to produce positive NPV).

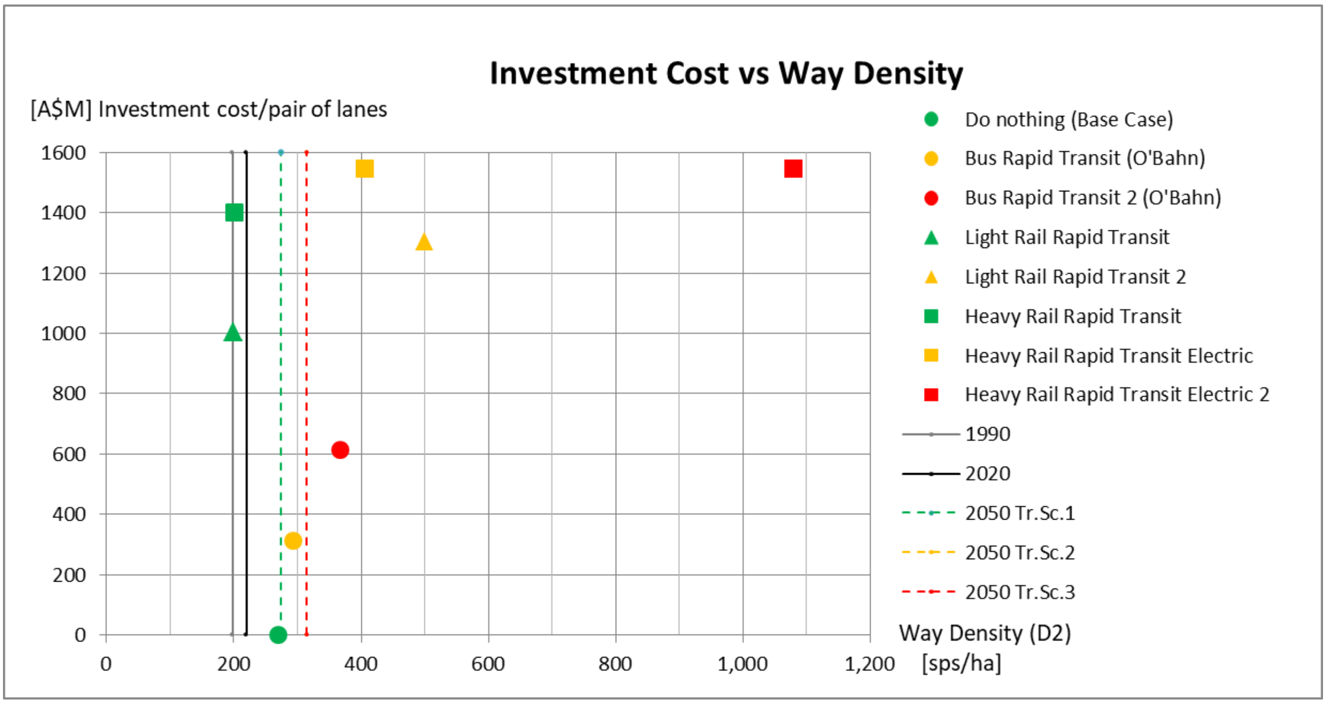

Figure 42-T.Scenarios in Investment Cost vs Way Density

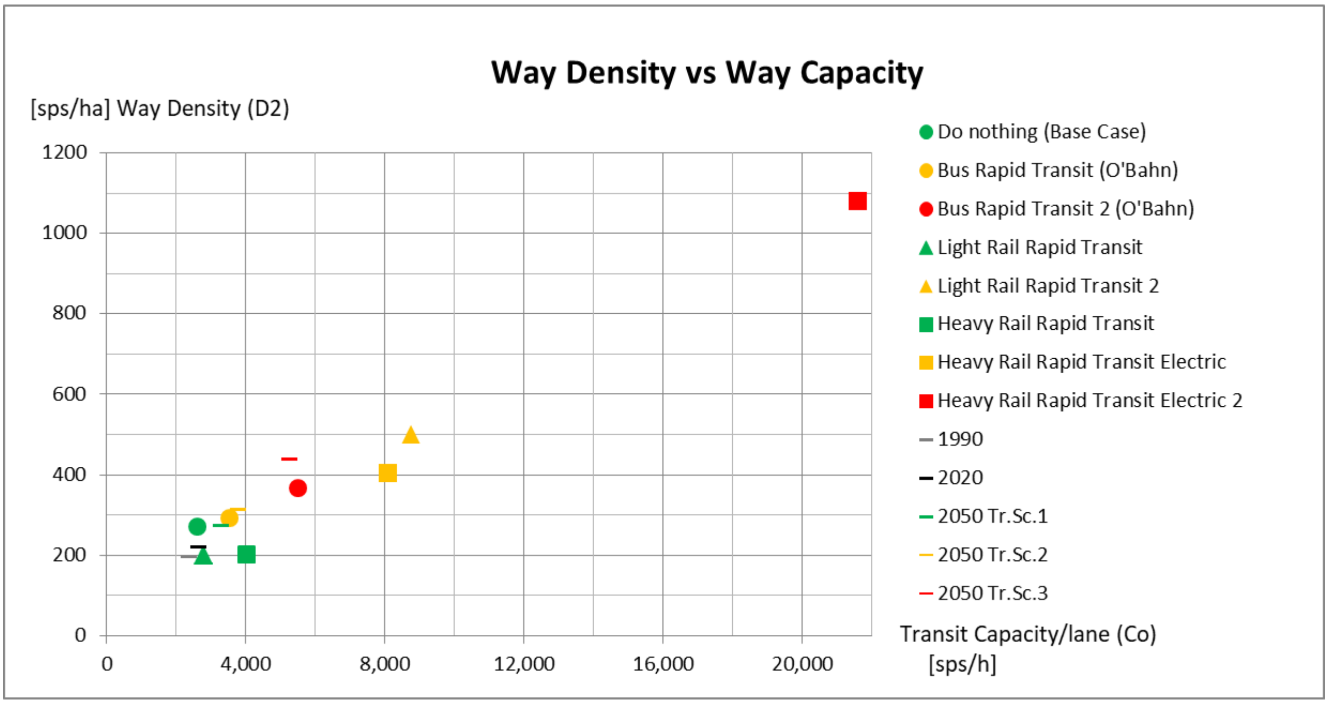

Figure 43-T.Scenarios in Way Density vs Way Capacity

It is noticed in the last two graphs that very high Capacity and Way Density (such as in Heavy Rail Transit) are not required for the Modbury corridor.

10.Conclusions.

This report makes a comprehensive example of the process required to perform a Benefit-Cost Analysis (BCA) in the stages of wider engineering issues to narrow options down to one specific project. In other words, the process developed in this thesis is required to select the best Public Transport alternative before moving forward to a more detailed engineering design.

There are publicly available relevant local guidelines and evaluation parameters to perform the BCA process. However, parameters and criteria specific to the project under evaluation need to be investigated and determined. Such as specific characteristics of Transit Mode options proposed and the development of a transport model suitable to estimate Volumes and Travel Times effects in the transport network. Transport Macro Models are considered adequate for these purposes. Probably Meso Models could be suitable as well. Conversely, Micro Models are not very practical for this purposes, due to the excessive modelling efforts required. However, Micro Models might be required for further design stages.

The options proposed are typical transit options, and the methodology is flexible enough to consider atypical or innovative options. However, the uncertainty of capital costs estimation may increase, potentially requiring more investigation in this regard.

In this thesis, feasible performance parameters were determined based on practical values of the current Transit System in Adelaide. Semi-rapid transit and Rapid transit were characterized by performance values. Evaluating only the demand and performance parameters, including capital costs, can be a good starting point to determine what Transit Mode option might be the best suitable.

Surveys were required to define many parameters of the evaluation, and the results were consistent with observations. On the other hand, Big Data, such as SCATS and Bluetooth data, can provide valuable information. However, Big Data processing, its errors and outliers filtering are difficult tasks that require considerable processing efforts, and yet results may not be the best suitable for some purposes.

The considerations and general evaluation parameters for the Benefit-Cost Analysis are generally similar for different projects and also past evaluations of the same project, such as with the O'Bahn. In addition, results were rather similar between past Ex-Ante evaluations and present Ex-Post evaluations, confirming that the O'Bahn project was the best option from a BCA perspective.

Something that could be considered with a dose of originality, is disaggregating benefits by demand/ periods, such as peak hours, inter-peak hours and off-peak hours. In this regard, it was noticed that transit alternatives for the Modbury Corridor produce most of the benefits in peak hours, at least 40% of the benefits, most of them in Transit Travel Time Savings. Furthermore, it was noticed that with higher congestion levels, the relevance of Congestion Reduction Benefits (or Car Travel Time savings) increases rapidly. In other words, transit projects are especially effective in peak hours and congested corridors.

The three most important components affecting the BCA are the Transit Capacity because it defines its feasibility, Capital costs and Travel Time saving at peak hour because are the most relevant components in NPV and BCR.

Finally, the Guided-Bus Rapid Transit is considered the best option from an economic point of view, for the expected demand growth in the next 30 years. Similar to the conclusions formulated in past evaluations, for the past 30 years, before the O'Bahn was constructed. Indeed, the O'Bahn produces a positive NPV in all evaluation considerations, which is considered rare for transit services. Even if the demand would grow more than expected, the Guided-BRT, or the current O'Bahn, is still the best option and still feasible as long as the performance is improved accordingly.

It is important to notice that the Ex-Ante evaluations are assuming a whole new construction for all the elements in the corridor (except for parking, which is out of this scope). Notwithstanding, the O'Bahn finished in 1990 is still operating and expected to continue operating, extending the horizon considered. This implies that the BCA of this thesis and also past evaluations are underestimating benefits. Although, it's general practice to consider no further than 30 years. Similarly, a real discount rate of 7% seems to be rather high, yet is the general practice to adopt it.

10.1. Future research possibilities.

Standard value parameters, such as Value of Time, residual value, option and non-use value, environmental costs and car operation costs could be further investigated, specifically for Adelaide.

Capital Costs is something worthwhile investigating with better precision, even during the alternative selection. Likewise, the transport model is very relevant too and deserves further development.

Fare and Operating costs are based on analyses made in 2009. Even if the values seem reasonable for the present day, it would be valuable to re-assess those figures.

Finally, there are research possibilities in developing generalizations, such as with Congestion functions suitable to measure Travel Time Variations/Impacts. For example, updating and re-calibrating the congestion functions used in MASTEM.

11.References

ACT Bus, 2012. *Scania K360UA 6×2/2 CB80 Specifications.* [Online]
Available at: https://www.actbus.net/scania-k360ua-cb80-specifications/
[Accessed 01 04 2020].

ACT Bus, 2014. *77 Scania K320UB from May 2014.* [Online]
Available at: https://www.actbus.net/forum/index.php?topic=3681.0
[Accessed 01 04 2020].

Adelaide Metro, 2020. *Adelaide Metro.* [Online]
Available at: https://adelaidemetro.com.au/Timetables2/Special-services/Adelaide-O-Bahn
[Accessed 01 04 2021].

Adelaide Metro, 2021. *Adelaide O-Bahn.* [Online]
Available at: https://adelaidemetro.com.au/Timetables2/Special-services/Adelaide-O-Bahn
[Accessed 05 2021].

Adelaide Metro, 2021. *O-Bahn and north-eastern suburbs network map.* [Online]
Available at:
https://adelaidemetro.com.au/content/download/109972/647687/version/2/file/NEW_NetworkMap_V12.pdf
[Accessed 01 04 2021].

Adelaide Metro, 2021. *Park 'n' Ride.* [Online]
Available at: https://adelaidemetro.com.au/Using-Adelaide-Metro/Park-n-Ride
[Accessed 01 04 2021].

Alejandro Tirachini, D. A. H. a. S. R. J.-D., 2009. *Comparing Operator and Users Costs of Light Rail, Heavy Rail and Bus Rapid Transit Over a Radial Public Transport Network.* Delft, Delft University of Technology (The Netherlands).

Alejandro Tirachini, D. A. H. a. S. R. J.-D., 2009. COMPARING OPERATOR AND USERS COSTS OF LIGHT RAIL, HEAVY RAIL AND BUS RAPID TRANSIT OVER A RADIAL PUBLIC TRANSPORT NETWORK. *Research in Transportation Economics,* 29(1), pp. 231-242.

Australian Bureau of Statistics, 2016. *2016 Census QuickStats.* [Online]
Available at:
https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/4GADE
[Accessed 01 04 2021].

Australian Bureau of Statistics, 2021. *6401.0 Consumer Price Index, Australia - All groups CPI; Australia,* s.l.: s.n.

Australian Bureau of Statistics, 2021. *Population Projections by Region, 2017-2066 : Population Projections by Region, South Australia.* [Online]
Available at: http://stat.data.abs.gov.au/Index.aspx?Queryid=1081#
[Accessed 01 04 2021].

Australian Government, 2016. *Gold Coast Light Rail - Stage 2.* [Online]
Available at:
https://investment.infrastructure.gov.au/projects/ProjectDetails.aspx?Project_id=060086-15QLD-NP
[Accessed 01 04 2021].

Australian Government, 2018. *Cost Estimation Guidance from the Department of Infrastructure, Regional Development and Cities.* Canberra ACT: Department of Infrastructure, Regional Development and Cities.

Australian Government, 2018. *Gawler Rail Line Electrification.* [Online]
Available at:
https://investment.infrastructure.gov.au/projects/ProjectDetails.aspx?Project_id=097117-17SA-NRP
[Accessed 01 04 2021].

Australian Government, 2019. *Flinders Link.* [Online]
Available at:
https://investment.infrastructure.gov.au/projects/ProjectDetails.aspx?Project_id=062838-15SA-NP
[Accessed 01 04 2021].

Australian Government, 2019. *Frankston to Baxter Rail Upgrade.* [Online]
Available at:
https://investment.infrastructure.gov.au/projects/ProjectDetails.aspx?Project_id=066079-16VIC-OFF#:~:text=The%20Preliminary%20Business%20Case%20examined,Mornington%20Peninsula%20ar

ea%20of%20Victoria.
[Accessed 01 04 2021].

Austroads, 2014. *Guide to Project Evaluation.* 2nd ed. Sydney: Austroads Inc..

AUSTROADS, 2014. *Guide to project evaluation.* Sydney: s.n.

Bray, D., 2010. *The Nature of Rationale of Urban Transport Policy in Australia.* Adelaide: University of South Australia.

Bray, D., 2013. *The Financial Cost of Transport in Adelaide: estimation and interpretation.* Brisbane, Australasian Transport Research Forum.

Cathy Macharis, A. B., 2014. - Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach. *Transport Policy.*

Chapman, P. C., 1992. *The Adelaide O'Bahn – How Dood In Practice?.* Canberra, Australasian Transport Research Forum conference,.

Charting Transport, 2017. *Trends in journey to work mode shares in Australian cities to 2016 (second edition).* [Online]
Available at: https://chartingtransport.com/tag/car-occupancy/
[Accessed 01 04 2021].

Chunqin Zhang, Z. J. Q. L. G. X., 2014. Performance evaluation of public transit systems using a combined evaluation method. *Transport Policy.*

Commonwealth of Australia, 2018. *Ex-post Economic Evaluation of National Road Investment Projects,* Canberra: Bureau of Infrastructure, Transport and Regional Economics (BITRE).

Dash Architects, 2015. *O-Bahn City Access Project,* Adelaide: s.n.

Department for Infrastructure and Transport, 2015. *O-Bahn City Access Project - Project Impact Report - Executive Summary,* Adelaide: s.n.

Department for Infrastructure and Transport, 2018. *O-Bahn City Access Project.* [Online]
Available at: https://dpti.sa.gov.au/infrastructure/public_transport_projects/o-bahn_city_access
[Accessed 01 04 2021].

Department for Infrastructure and Transport, 2021. *Traffic Volumes.* [Online]
Available at: https://dpti.sa.gov.au/traffic_volumes
[Accessed 01 04 2021].

Department of Planning, Transport and Infrastructure, 2019. *2018-19 Annual Report.* Adelaide: s.n.

Department of Transport (SA) and P.G. Pak-Poy & Associates Pty. Ltd., 1974. *Study of Public Transport Alternatives for the Modbury Corridor,* Adelaide: s.n.

Department of Transport (SA), 1979. *Northeast Light Rail Line – Economic & Financial Assessment,* Adelaide: s.n.

Department of Transport (SA), 1980. *Public Transport in The Northeast Area of Adelaide,* Adelaide: s.n.

Department of Transport (SA), 1988. *Northeast Busway Before and After Study – Final Report: Evaluation of the Busway,* Adelaide: s.n.

Department of Transport (SA), 1991. *An Economic Evaluation of the Northeast Busway in Adelaide,* Adelaide: s.n.

Department of Transport and Main Roads QLD, 2013. *Traffic and Road Use Management - Volume 1 – Guide to Traffic Management.* Brisbane: Queensland Government.

DPTI, 2018. 3000 Series Railcar Upgrade Catch Point. *DPTI News,* Issue 244, 245, pp. 4,12,13.

Dr David Gargett, D. D. C., 2002. *Predicting Traffic Growth in Australian Cities,* Adelaide: Bureau of Transport and Regional Economics.

FAO, 2020. *Tool for Designing, Monitoring and Evaluating.* [Online]
Available at: http://www.fao.org/in-action/herramienta-administracion-tierras/module-5/practical-evaluation-guide/introduction-cba/en/
[Accessed 01 04 2021].

Google , 2021. *Google Maps.* [Online]
Available at: https://www.google.com/maps/place/Adelaide+SA+5000/@-34.9256337,138.5657491,13z/data=!3m1!4b1!4m5!3m4!1s0x6ab0ced7a303a4e7:0xb38d70584e1c3

e53!8m2!3d-34.9285007!4d138.6007245
[Accessed 01 04 2021].

Government of South Australia, 1980. *Manual for Economic Evaluation of Public Transport Projects.* Adelaide: s.n.

Government of South Australia, 2013. *The Integrated Transport and Land Use Plan.* Adelaide: s.n.

Government of South Australia, 2014. *Guidelines for the evaluation of public sector initiatives.* Adelaide: Department of Treasury and Finance.

Infrastructure and Transport Ministers, 2020. *Australian Transport Assessment and Planning Guidelines - PV5 – Environmental parameter values.* Canberra: Department of Infrastructure, Transport, Regional Development and Communications.

Infrastructure Australia, 2016. *Australian Infrastructure Plan, Priorities for our nation's future, report 2016.* s.l.:s.n.

Infrastructure Australia, 2018. - *Assessment Framework for Initiatives and Projects to be included in the Infrastructure Priority List.* Canberra: Commonwealth of Australia.

Infrastructure Australia, 2018. *METRONET: Thornlie-Cockburn Link.* [Online]
Available at: https://www.infrastructureaustralia.gov.au/sites/default/files/2019-06/Project-Evaluation-Summary-METRONET-TCL_1.pdf
[Accessed 01 04 2021].

Infrastructure Australia, 2018. *METRONET: Yanchep Rail Extension.* [Online]
Available at: https://www.infrastructureaustralia.gov.au/sites/default/files/2019-06/Project-Evaluation-Summary-METRONET-YRE_0.pdf
[Accessed 01 04 2021].

Infrastructure Australia, 2018. *Outer Urban Public Transport, Improving accessibility in lower-density areas.* s.l.:s.n.

Infrastructure Australia, 2019. *An Assessment of Australia's Future Infrastructure Needs - The Australian Infrastructure Audit 2019.* s.l.:s.n.

Infrastructure Australia, 2019. *Gold Coast Light Rail: Stage 3A.* [Online]
Available at: https://www.infrastructureaustralia.gov.au/projects/gold-coast-light-rail-stage-3a
[Accessed 01 04 2021].

Infrastructure Australia, 2020. *Byford Rail Extension.* [Online]
Available at: https://www.infrastructureaustralia.gov.au/sites/default/files/2020-12/Byford%20evaluation%20summary.pdf
[Accessed 01 04 2021].

Infrastructure Australia, 2020. *Infrastructure Priority List, Update to the Febraru 2020.* s.l.:s.n.

Infrastructure Australia, 2020. *Past Evaluations.* [Online]
Available at: https://www.infrastructureaustralia.gov.au/project-evaluations/past-evaluations
[Accessed 01 04 2021].

Infrastructure Magazine, 2017. *O-Bahn City Access Project complete.* [Online]
Available at: https://infrastructuremagazine.com.au/2017/12/13/o-bahn-city-access-project-complete/
[Accessed 01 04 2020].

Infrastructure SA, 2020. *20-YEAR STATE INFRASTRUCTURE STRATEGY.* s.l.:s.n.

James J. Laird, A. J. V., 2017. Transport investment and economic performance: Aframework for project appraisal. *Transport Policy.*

Leurent, F., 2011. Transport Capacity constraints on the mass transit system: a systemic analysis. *Eur. Transp. Res. Rev.,* Issue 3:11-21.

Local Government Association of South Australia, 2021. *SA councils list and map.* [Online]
Available at: https://www.lga.sa.gov.au/sa-councils/councils-listing
[Accessed 01 04 2021].

Margaret Starrs, 1982. *Economic Evaluation of the O-Bahn,* Adelaide: s.n.

Masoud Fadaei, O. C., 2016. Evaluating the impacts and benefits of public transport design and operational measures. *Transport Policy.*

Massachusetts Bay Transportation Authority, 2021. *SILVER LINE SL1.* [Online]
Available at: https://www.mbta.com/schedules/741/line
[Accessed 01 04 2021].

Mathew, P. T. V., 2021. *Department of Civil Engineering, IIT Bombay.* [Online]
Available at:
https://www.civil.iitb.ac.in/tvm/nptel/572_Delay_A/web/web.html#:~:text=Signalized%20intersections%20are%20the%20important%20points%20or%20nodes,the%20quality%20of%20operations%20is%20a%20difficult%20task.
[Accessed 01 04 2021].

McNally, M. G., 2000. *The Four Step Model.* California: University of California.

Metro Adelaide, 2020. *Fares.* [Online]
Available at: https://adelaidemetro.com.au/Tickets-Fares/Fares
[Accessed 01 04 2021].

Metro Report International, 2019. *Adelaide A-City fleet expansion.* [Online]
Available at: https://www.railwaygazette.com/modes/adelaide-a-city-fleet-expansion/48823.article
[Accessed 01 04 2020].

National Institute of Standards and Technology (US), 2021. *Engineering Statistics Handbook - 7.1.6 What are outliers in the data.* [Online]
Available at: https://www.itl.nist.gov/div898/handbook/prc/section1/prc16.htm
[Accessed 01 04 2021].

NEF Consulting, 2020. *SOCIAL AND ENVIRONMENTALCOST-BENEFIT ANALYSIS (SCBA).* [Online]
Available at: https://www.nefconsulting.com/what-we-do/evaluation-impact-assessment-2013/social-environmental-cost-benefit-analysis-scba/
[Accessed 01 04 2021].

Nicholas Holyoak, M. T. L. O. a. J. G., 2005. *Development of a New Strategic Transport Planning Model for Adelaide.* [Online]
Available at: : https://www.researchgate.net/publication/267370880

Ni, D., 2006. *A FRAMEWORK FOR NEW GENERATION TRANSPORTATION SIMULATION.* Amherst, University of Masachusetts.

Nils O.E. Olsson, H. P. K. A. R. M. V., 2010. Influence of reference points in ex post evaluations of rail infrastructure projects. *Transport Policy.*

Public Transport Victoria, 2020. *Timetables.* [Online]
Available at: https://www.ptv.vic.gov.au/timetables
[Accessed 01 04 2021].

R. Khraibani, A. d. P. N. I., 2016. - A new evaluation and decision making framework investigating the elimination-by-aspects model in the context of transportation project's investment choices. *Transport Policy.*

Robbie Napper, P. T., 2016. Life Cycle Cost of Australian Route Buses. *Monash Business School - Member Bulleting,* Issue 16, pp. 18-30.

Rodrigue, J.-P., 2020. *The Geography of Transport System.* 5th ed. New York: Routledge.

Royal Automobile Club of Victoria, 2019. *Car Running Costs.* [Online]
Available at: https://www.racv.com.au/on-the-road/buying-a-car/car-running-costs.html
[Accessed 01 04 2021].

Royal Institution of Chartered Surveyors (RICS), 2011. *Cost analysis and benchmarking.* 1st ed. London: Park Communications Limited.

SCATS-NSW Government, 2021. *SCATS.* [Online]
Available at: https://www.scats.nsw.gov.au/about-us-0
[Accessed 01 04 2021].

Scott, G., 2020. *Investopedia - Fisher Effect Definition.* [Online]
Available at: https://www.investopedia.com/terms/f/fishereffect.asp
[Accessed 01 04 2021].

Scrafton, D. B. a. D., 2019. The Adelaide O-Bahn: evolution, operation and lessons. In: F. Ferbrache, ed. *Developing Bus Rapid Transit The Value of BRT in Urban Spaces.* Cheltenham, Gloucestershire: Edward Elgar Publishing, p. 14.

South Australian Government Data Directort, 2017. *Bluetooth Vehicle Origins and Destinations (sample only).* [Online]
Available at: https://data.sa.gov.au/data/dataset/bluetooth-vehicle-origins-and-destinations-sample-

only
[Accessed 01 04 2021].

South Australian Government Data directory, 2019. *Travel Time Performance Indicators.* [Online]
Available at: https://data.sa.gov.au/data/dataset/travel-time-performance-indicators
[Accessed 01 04 2021].

South Australian Government Data Directory, 2021. *Bluetooth Detection Sites.* [Online]
Available at: https://data.sa.gov.au/data/dataset/bluetooth-detection-sites
[Accessed 01 04 2021].

Trading Economics, 2021. *Australia - Real Interest Rate.* [Online]
Available at: https://tradingeconomics.com/australia/real-interest-rate-percent-wb-data.html#:~:text=Real%20interest%20rate%20(%25)%20in,compiled%20from%20officially%20recognized%20sources.
[Accessed 01 04 2021].

Transport and Infrastructure Council, 2018. *Australian Transport Assesment and Planning Guidelines - M1 – Public Transport.* Canberra ACT: Australian Department of Infrastrucutre, Regional Development and Cities.

Transport and Main Roads (QLD), 2021. *Cost-Benefit Analysis Manual – Road Projects.* 1.1 ed. Sydney: Queensland Government.

Transport for NSW, 2016. *Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives.* Sydney: NSW Government.

Transport NSW, 2020. *Routes and timetables.* [Online]
Available at: https://transportnsw.info/routes
[Accessed 01 04 2021].

Transportation Research Board, 2013. *Transit Capacity and Quality of Service Manual.* 3rd ed. Washington: National Academy of Sciences.

Travers Morgan Pty. Ltd., 1977. *North East Area – Public Transport Review – Economic Assessment ,* Adelaide: s.n.

U.S. Department of Transportation, 1992. *Estimation of Operating and Maintenance Costs of Transit Systems.* Washington: Federal Transit Administration.

U.S. Federal Transit Administration, 2007. *Useful Life of Transit Buses and Vans.* Washington: U.S. Department of Transportation.

Veitch Lister Consulting, 2019. *Transport Modelling Report for Adelaide,* Adelaide: Infrastructure Australia.

Victoria Transport Policy Institute, 2020. *Evaluating Public Transit Benefits and Costs – Best Practices Guidebook.* Melbourne: Todd Alexander Litman.

Vuchic, V. R., 2007. *URBAN TRANSIT SYSTEMS AND TECHNOLOGY.* New Jersey: John Wiley & Sons, Inc..

Appendix A - O-Bahn and north-eastern suburbs network map

Table 66-Bus Service Routes using the O'Bahn (Adelaide Metro, 2021).

Service Routes
Route500 - Elizabeth Interchange to City
Route501 - Mawson Interchange to City
Route502 - Salisbury Interchange to City
Route502X - Salisbury Interchange to City
Route503 - Tea Tree Plaza Interchange to City
Route506 - Tea Tree Plaza Interchange to City
Route507 - Tea Tree Plaza Interchange to City
Route528 - Northgate to City
Route530 - Firle to City
Route540 - Tea Tree Plaza Interchange to City
Route541 - Golden Grove Interchange & Fairview Park to City
Route541X - Golden Grove Interchange to City
Route542X - Fairview Park to City
Route543X - Surrey Downs to City
Route544 - Golden Grove Interchange to City
Route544X - Golden Grove Interchange to City
Route545X - Golden Grove Interchange to City
Route546X - Para Hills to City
Route548 - Greenwith & Tea Tree Plaza Interchange to City
Route556 - Tea Tree Plaza Interchange to City
Route557 - Tea Tree Plaza Interchange to City
Route559 - Tea Tree Plaza Interchange to Paradise Interchange
Route578 - Newton & Athelstone to City
RouteC1 - Golden Grove Interchange to City
RouteC1X - Golden Grove Interchange to City
RouteC2 - Greenwith to City
RouteC2X - Greenwith to City
RouteJ1 - Elizabeth Interchange to Adelaide Airport & Glenelg
RouteJ2 - Greenwith to Adelaide Airport & Harbour Town
RouteM44 - Marion Centre Interch. to Golden Grove Interch.
RouteN502 - Sat. PM - Sun. AM Salisbury Interchange to City
RouteN541 - Sat. PM - Sun. AM City to Fairview Park
RouteN542 - Fairview Park Tea Tree Plaza Interchange

The following Map is extracted from Adelaide Metro Web Page, and shows the Bus lines travelling through the O'Bahn, and Bus lines travelling across the O'Bahn's interchanges (Adelaide Metro, 2021):

Figure 44- O-Bahn and north-eastern suburbs network map (Adelaide Metro, 2021)

[figure removed due to copyright restriction]

Appendix B – Cost Benchmarking Data

Refer to section 3.3 Options Capital Costs for details about the reference projects and Benchmark Cost selection.

Summary of Cost Data analysed is listed below:

Table 67- Summary of Cost Data for Cost Benchmarking

	Year	Cost (M$)	Length (km)	Lanes	Benchmark (M$/Lane-Km)	CPI Index	Benchmark - prices Dec-2020 (M$/Lane-Km)
Light Rail (Electric)							
Gold Coast Light Rail: Stage 3A	Aug-19	536	6.7	2	40.00	115.0	40.8
Gold Coast Light Rail - Stage 2	Jun-16	420	7.3	2	28.77	108.6	31.0
Heavy Rail							
METRONET: Thornlie-Cockburn Link	Nov-18	716	16	2	22.38	114.1	23.0
METRONET: Yanchep Rail Extension	Oct-18	532	14.5	2	18.34	114.7	18.7
for freigth	Jun-17	5 to 15 M/km			10.00	110.7	10.6
Heavy Rail (electric)							
Byford Rail Extension	Oct-20	650	7.5	2	43.33	116.2	43.7
Frankston to Baxter Rail Upgrade Preliminary Business Case	Jun-18	450	8	1	56.25	113.0	58.3
Flinders Link	Jun-19	141	0.65	1	216.92	114.8	221.5
Electrification							
Gawler Rail Line Electrification	Aug-18	440	42	2	5.24	113.5	5.4
O Bahn	Dec-86	100	12	2	4.17	48.25	10.1
Busway	Nov-77	43	12	2	1.79	21.0	10.0
Light Rail	Nov-77	51	12	2	2.13	21.0	11.9
Heavy Rail	Nov-77	160	12	2	6.67	21.0	37.2
Freeway	Nov-77	58.6	12	4	1.22	21.0	6.8
Land min	Nov-77	6	12	1	0.50	21.0	2.8
Land max	Nov-77	8	12	1	0.67	21.0	3.7

Land avg lower	Dec-06	0.25	0.02	1	12.50	86.6	16.9
Land avg upper	Dec-10	0.49	0.02	1	24.50	96.9	29.6
ATAP Guidelines							
Railway track	May-18	40	1	2	20.0	113	20.7
Railway track	May-18	80	1	2	40.0	113	41.5
Bore Tunnel	May-18	60	1	2	30.0	113	31.1
O bahn Tunnel	Dec-16	160	1	2	80.0	110	85.2
Light Rail (electrified)	May-18	100	1	2	50.0	113	51.9
Light Rail (electrified)	May-18	150	1	2	75.0	113	77.8
Dedicated Bus Lane	May-18	5	1	2	2.5	113	2.6
Dedicated Bus Lane	May-18	20	1	2	10.0	113	10.4
Railway Station - Surface	May-18				15	113	15.6
Railway Station - Surface	May-18				40	113	41.5
Railway Station - Underground	May-18				30	113	31.1
Railway Station - Underground	May-18				60	113	62.2
Light Rail stop	May-18				0.5	113	0.5
Light Rail stop	May-18				2.5	113	2.6
Interchange	May-18				10	113	10.4
Interchange	May-18				15	113	15.6

12. Note: Dec-2020 - CPI index: 117.2 (Australian Bureau of Statistics, 2021)

Appendix C – Car Travel Time Surveys

The following Car Travel Time surveys are based on a standard surveys as detailed in Traffic Studies and Analysis (Department of Transport and Main Roads QLD, 2013). The survey basically consists on measuring the travel time between control sections. Then, in addition, the Traffic Volume is estimated (based on Volumes determined in section 5, and hourly variation determined in section 6):

1)

	Direction:	Date:	Weekday:	Time:			
	(through NER) CBD to Tea Tree Plaza	6/05/2021	Thursday	17:00			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	3.8	3.8	20.8	2.9
74-282	North East Rd. & Ascot Ave.	6000	4700	14.2	10.5	26.9	2.2
282-206	North East Rd. & Sudhlz Rd.	10200	4200	25.2	11.0	23.0	2.6
206-498	North East R.d & McIntyre Rd.	13600	3400	28.9	3.7	55.6	1.1

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.048	773
74-282	43251	1.05	0.048	2161
282-206	43865	1.05	0.048	2192
206-498	45651	1.05	0.048	2281

2)

	Direction:	Date:	Weekday:	Time:			
	(through NER) Tea Tree Plaza to CBD	6/05/2021	Thursday	17:35			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		24.9			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	19.4	5.5	14.3	4.2
74-282	North East Rd. & Ascot Ave.	6000	4700	10.9	8.5	33.0	1.8
282-206	North East Rd. & Sudhlz Rd.	10200	4200	5.1	5.8	43.4	1.4
206-498	North East R.d & McIntyre Rd.	13600	3400	0.0	5.1	40.4	1.5

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.034	545
74-282	43251	1.05	0.034	1524
282-206	43865	1.05	0.034	1546
206-498	45651	1.05	0.034	1609

3)

Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Direction:	Date:	Weekday:	Time:			
	(through NER) CBD to Tea Tree Plaza	7/05/2021	Friday	0:20			
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	3.6	3.6	22.0	2.7
74-282	North East Rd. & Ascot Ave.	6000	4700	8.4	4.9	57.9	1.0
282-206	North East Rd. & Sudhlz Rd.	10200	4200	12.8	4.4	57.1	1.1
206-498	North East R.d & McIntyre Rd.	13600	3400	16.5	3.7	55.6	1.1

Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
	Traffic Volume Estimates			
3020-74	15463	1.10	0.006	99
74-282	43251	1.10	0.006	276
282-206	43865	1.10	0.006	280
206-498	45651	1.10	0.006	292

4)

Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Direction:	Date:	Weekday:	Time:			
	(through NER) Tea Tree Plaza to CBD	7/05/2021	Friday	0:41			
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		17.1			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	15.1	2.0	39.7	1.5
74-282	North East Rd. & Ascot Ave.	6000	4700	9.0	6.1	46.2	1.3
282-206	North East Rd. & Sudhlz Rd.	10200	4200	3.8	5.2	48.8	1.2
206-498	North East R.d & McIntyre Rd.	13600	3400	0.0	3.8	53.4	1.1

Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
	Traffic Volume Estimates			
3020-74	15463	1.10	0.003	56
74-282	43251	1.10	0.003	155
282-206	43865	1.10	0.003	158
206-498	45651	1.10	0.003	164

5)

	Direction:	Date:	Weekday:	Time:			
	(through NER) CBD to Tea Tree Plaza	11/05/2021	Tuesday	7:30			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	3.3	3.3	23.6	2.5
74-282	North East Rd. & Ascot Ave.	6000	4700	11.0	7.7	36.5	1.6
282-206	North East Rd. & Sudhlz Rd.	10200	4200	17.2	6.1	41.1	1.5
206-498	North East R.d & McIntyre Rd.	13600	3400	21.9	4.7	43.6	1.4

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.018	284
74-282	43251	1.05	0.018	795
282-206	43865	1.05	0.018	807
206-498	45651	1.05	0.018	839

6)

	Direction:	Date:	Weekday:	Time:			
	(through NER) Tea Tree Plaza to CBD	11/05/2021	Tuesday	8:00			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		37.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	32.0	5.0	15.6	3.8
74-282	North East Rd. & Ascot Ave.	6000	4700	15.0	17.0	16.6	3.6
282-206	North East Rd. & Sudhlz Rd.	10200	4200	4.2	10.8	23.3	2.6
206-498	North East R.d & McIntyre Rd.	13600	3400	0.0	4.2	48.6	1.2

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.044	721
74-282	43251	1.05	0.044	2017
282-206	43865	1.05	0.044	2046
206-498	45651	1.05	0.044	2129

7)

Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Direction:	Date:	Weekday:	Time:			
	(through NER) CBD to Tea Tree Plaza	11/05/2021	Tuesday	17:09			
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	8.5	8.5	9.2	6.6
74-282	North East Rd. & Ascot Ave.	6000	4700	20.0	11.5	24.6	2.4
282-206	North East Rd. & Sudhlz Rd.	10200	4200	26.2	6.2	40.4	1.5
206-498	North East R.d & McIntyre Rd.	13600	3400	30.1	3.9	52.8	1.1

Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
	Traffic Volume Estimates			
3020-74	15463	1.05	0.048	773
74-282	43251	1.05	0.048	2161
282-206	43865	1.05	0.048	2192
206-498	45651	1.05	0.048	2281

8)

Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Direction:	Date:	Weekday:	Time:			
	(through NER) Tea Tree Plaza to CBD	11/05/2021	Tuesday	17:44			
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		22.7			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	18.9	3.8	20.4	2.9
74-282	North East Rd. & Ascot Ave.	6000	4700	10.7	8.1	34.7	1.7
282-206	North East Rd. & Sudhlz Rd.	10200	4200	5.5	5.3	47.8	1.3
206-498	North East R.d & McIntyre Rd.	13600	3400	0.0	5.5	37.3	1.6

Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
	Traffic Volume Estimates			
3020-74	15463	1.05	0.034	545
74-282	43251	1.05	0.034	1524
282-206	43865	1.05	0.034	1546
206-498	45651	1.05	0.034	1609

9)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) CBD to Tea Tree Plaza	7/05/2021	Friday	1:11			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	2.5	2.5	31.6	1.9
74-77	Lower North East Rd. & Portrush Rd.	6000	4700	6.7	4.3	66.4	0.9
77-265	Lower North East Rd. & Darley Rd.	10200	4200	11.9	5.2	48.3	1.2
265-422	Lower North East Rd. & Valley Rd.	13600	3400	16.1	4.2	49.0	1.2

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.10	0.003	59
74-77	31943	1.10	0.003	121
77-265	40630	1.10	0.003	154
265-422	29745	1.10	0.003	113

10)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) Tea Tree Plaza to CBD	7/05/2021	Friday	1:30			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		14.7			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	11.9	2.8	27.5	2.2
74-77	Lower North East Rd. & Portrush Rd.	4700	3400	8.2	3.7	55.6	1.1
77-265	Lower North East Rd. & Darley Rd.	8600	3900	4.2	4.0	58.5	1.0
265-422	Lower North East Rd. & Valley Rd.	12600	4000	0.0	4.2	57.4	1.0

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.10	0.002	34
74-77	31943	1.10	0.002	71
77-265	40630	1.10	0.002	91
265-422	29745	1.10	0.002	66

11)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) CBD to Tea Tree Plaza	11/05/2021	Tuesday	18:09			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	3.7	3.7	21.4	2.8
74-77	Lower North East Rd. & Portrush Rd.	6000	4700	15.2	11.5	24.5	2.4
77-265	Lower North East Rd. & Darley Rd.	10200	4200	20.4	5.3	47.7	1.3
265-422	Lower North East Rd. & Valley Rd.	13600	3400	25.7	5.2	39.1	1.5

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.034	558
74-77	31943	1.05	0.034	1152
77-265	40630	1.05	0.034	1466
265-422	29745	1.05	0.034	1073

12)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) Tea Tree Plaza to CBD	11/05/2021	Tuesday	18:39			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		17.9			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	14.3	3.6	21.6	2.8
74-77	Lower North East Rd. & Portrush Rd.	4700	3400	9.6	4.7	43.4	1.4
77-265	Lower North East Rd. & Darley Rd.	8600	3900	4.6	5.0	47.3	1.3
265-422	Lower North East Rd. & Valley Rd.	12600	4000	0.0	4.6	52.2	1.2

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.027	442
74-77	31943	1.05	0.027	913
77-265	40630	1.05	0.027	1162
265-422	29745	1.05	0.027	850

13)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) CBD to Tea Tree Plaza	12/05/2021	Wednesday	8:20			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		0.0			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	3.6	3.6	22.0	2.7
74-77	Lower North East Rd. & Portrush Rd.	6000	4700	8.3	4.7	59.8	1.0
77-265	Lower North East Rd. & Darley Rd.	10200	4200	14.0	5.7	44.3	1.4
265-422	Lower North East Rd. & Valley Rd.	13600	3400	19.1	5.2	39.6	1.5

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.025	402
74-77	31943	1.05	0.025	831
77-265	40630	1.05	0.025	1058
265-422	29745	1.05	0.025	774

14)

	Direction:	Date:	Weekday:	Time:			
	(through LNER) Tea Tree Plaza to CBD	12/05/2021	Wednesday	8:40			
Link	Location	Chainage [m]	Link Length [m]	Stopwatch record [min]	Section Travel Time [min]	Length/TT [km/h]	TT/Length [min/km]
	Hindmarsh Square (Grenfell St. & Pulteney St.)	0		24.5			
3020-74	North Terrace/Botanic Road & Princess Highway/Dequetteville Terrace	1300	1300	20.0	4.5	17.4	3.4
74-77	Lower North East Rd. & Portrush Rd.	4700	3400	11.2	8.8	23.1	2.6
77-265	Lower North East Rd. & Darley Rd.	8600	3900	5.2	6.0	38.8	1.5
265-422	Lower North East Rd. & Valley Rd.	12600	4000	0.0	5.2	46.6	1.3

	Traffic Volume Estimates			
Link	AADT Estim.:	Weekly Coef:	Time Coef:	Volume Estim.:
3020-74	15463	1.05	0.039	638
74-77	31943	1.05	0.039	1318
77-265	40630	1.05	0.039	1676
265-422	29745	1.05	0.039	1227

Appendix D – O'Bahn observations

Several observations were performed in the O'Bahn system. Even if no precise measurement or standard surveys were conducted, the observations were sufficient to confirm that the parameters adopted for evaluation were reasonable.

1) Regarding performance and capacity (Section 3.2)

(19/05/2021)

It was observed a max frequency of up to 4 buses in one minute at peak hours. However, that frequency is not maintained for long periods.

The timetable is observed as very reliable. In fact, buses waiting at the station in peak hours were observed.

Hence, it is reasonable to adopt the max frequency observed in the timetable for lines driving through the O'Bahn.

Most of the bus lines that drive through all O'Bahn stations are Articulated Buses at peak hours. Approximately 90% (in accordance with TU assumptions).

Figure 45-Bus type mostly observed at peak hours (19/05/2021)

Speed in the O'Bahn is perceived as very fast, much higher than 40 km/h. However, considerable delays or even waiting times at stations were observed.

The number of seats and the potential number of people standing (both making Crush Capacity) is consistent with the values adopted. For instance, 44 seat capacity and 66 crush capacity was counted in one regular bus; 64 seat capacity and approximately 90 crush capacity was estimated in one articulated bus.

2) Regarding trip Assignment (Section 5.4)

(19/05/2021)

It was observed people transferring buses, with very little delay, just to continue through the O'Bahn.

It was observed indeed, a small fraction of passengers descending in Klemzing, even more at Paradise, but half or slightly more than half of the passengers were reaching Tea Tree Plaza (some of them would remain in the bus, but that is out of scope). This is consistent with the Transit Trip assignment adopted in Section 5.4

Figure 46-Observation of passengers remaining after Paradise Interchange (19/05/2021)

This is also coherent with the number of bus feeders and the number of parking spots offered in each interchange.

Frequent users and Bus drivers were consulted in this regard, and they agreed with a 10%-35%-55% (Klemzing-Paradise-TTP) distribution.

3) Regarding patronage volume and capacity (Chapter 8 and 9)

(19/05/2021)

During Peak hours, it was observed the limited possibility of operational improvement in the CBD Area. Even if Frequency could be slightly improved, higher Normal Operating Speed and higher TU capacity seem difficult to be suitable in current conditions.

During Peak hours, in the section from CBD Area to Klemzing Interchange (with 100% of the passengers considered), Seat capacity was observed depleted in many cases (buses and articulated buses), but it was not perceived to be too close to Crush Capacity in articulated buses. However, this was observed only for short periods in the very peak moments.

Figure 47-High Demand/Capacity at peak hour (19/05/2021)

These observations are coherent with assumptions adopted and results obtained in this thesis.

However, even if the parameters adopted are consistent with observations, it is perceived that the O'Bahn system in the current condition can offer a slightly higher capacity. In other words, it is possible that the capacity adopted for the O'Bahn might be slightly underestimated.

Appendix E – Trip Assignment Results

Table 68-Trip Assignment – T.Scenario 1

	North East Road - AADT [veh/day]				Lower North East Road - AADT [veh/day]				Modbury Corridor Patronage [passengers/day]		
Year	3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422	Former users	Diverted Users (DU)	New Diverted Users (NDU)
1990	9457	26452	26827	27919	9457	19536	24849	18192	20800	2000	0
1991	9504	26585	26963	28060	9504	19634	24974	18284	21029	2337	0
1992	9588	26819	27200	28307	9588	19807	25194	18444	21260	2362	0
1993	9851	27554	27945	29082	9851	20350	25884	18950	21494	2388	0
1994	10018	28022	28419	29576	10018	20695	26323	19271	21730	2414	0
1995	10436	29191	29605	30810	10436	21558	27421	20075	21969	2441	0
1996	10782	30159	30587	31832	10782	22274	28331	20741	22211	2468	0
1997	10890	30460	30892	32149	10890	22496	28614	20948	22455	2495	0
1998	11355	31762	32213	33524	11355	23458	29837	21844	22702	2522	0
1999	11499	32163	32619	33947	11499	23753	30214	22119	22952	2550	0
2000	11725	32798	33263	34617	11725	24222	30810	22556	23205	2578	0
2001	11725	32798	33263	34617	11725	24222	30810	22556	23460	2607	0
2002	12000	33566	34042	35428	12000	24789	31532	23084	23718	2635	0
2003	12358	34568	35058	36485	12358	25529	32473	23773	23979	2664	0
2004	12728	35603	36108	37578	12728	26294	33445	24485	24243	2694	0
2005	13063	36538	37057	38565	13063	26985	34324	25128	24509	2723	0
2006	13266	37106	37633	39164	13266	27404	34857	25519	24779	2753	0
2007	13469	37674	38208	39764	13469	27823	35391	25909	25051	2783	0
2008	13648	38175	38717	40292	13648	28193	35861	26254	25327	2814	0
2009	13827	38676	39225	40821	13827	28563	36332	26599	25606	2845	0
2010	14018	39210	39767	41385	14018	28958	36834	26966	25887	2876	0
2011	14173	39644	40207	41843	14173	29279	37242	27265	26172	2908	0
2012	14340	40112	40681	42337	14340	29624	37681	27586	26460	2940	0
2013	14484	40513	41088	42760	14484	29920	38058	27862	26751	2972	0
2014	14627	40914	41494	43183	14627	30216	38434	28137	27045	3005	0
2015	14770	41314	41901	43606	14770	30512	38811	28413	27343	3038	0
2016	14913	41715	42307	44029	14913	30808	39187	28689	27644	3072	0
2017	15069	42149	42747	44487	15069	31129	39595	28987	27800	3089	0
2018	15200	42517	43120	44875	15200	31400	39940	29240	27900	3100	0
2019	15331	42884	43493	45263	15331	31671	40285	29493	28141	3127	0
2020	15463	43251	43865	45651	15463	31943	40630	29745	28382	3154	0
2021	15563	43532	44149	45946	15563	32150	40893	29938	28566	3174	0
2022	15693	43894	44517	46329	15693	32417	41234	30187	28804	3200	0
2023	15825	44266	44894	46721	15825	32692	41583	30443	29048	3228	0
2024	15961	44646	45279	47122	15961	32972	41940	30704	29297	3255	0
2025	16099	45031	45670	47529	16099	33257	42302	30969	29550	3283	0
2026	16239	45423	46068	47943	16239	33547	42671	31239	29807	3312	0

2027	16382	45823	46473	48364	16382	33842	43046	31514	30069	3341	0
2028	16524	46221	46877	48785	16524	34136	43420	31787	30331	3370	0
2029	16665	46615	47276	49200	16665	34427	43790	32058	30589	3399	0
2030	16804	47004	47671	49611	16804	34714	44155	32326	30845	3427	0
2031	16942	47388	48061	50017	16942	34998	44517	32590	31097	3455	0
2032	17077	47768	48445	50417	17077	35278	44873	32851	31346	3483	0
2033	17211	48141	48825	50812	17211	35554	45224	33108	31591	3510	0
2034	17342	48510	49198	51200	17342	35826	45570	33361	31833	3537	0
2035	17472	48872	49566	51583	17472	36094	45910	33611	32071	3563	0
2036	17600	49230	49928	51961	17600	36358	46246	33857	32305	3589	0
2037	17727	49584	50287	52334	17727	36619	46579	34100	32538	3615	0
2038	17852	49934	50643	52704	17852	36878	46908	34341	32767	3641	0
2039	17976	50281	50994	53070	17976	37134	47233	34580	32995	3666	0
2040	18098	50624	51342	53432	18098	37387	47556	34815	33220	3691	0
2041	18220	50963	51687	53790	18220	37638	47875	35049	33443	3716	0
2042	18340	51300	52028	54146	18340	37887	48191	35281	33664	3740	0
2043	18460	51634	52367	54498	18460	38133	48505	35510	33883	3765	0
2044	18578	51965	52703	54848	18578	38378	48816	35738	34100	3789	0
2045	18696	52295	53037	55195	18696	38621	49125	35965	34316	3813	0
2046	18813	52622	53369	55541	18813	38863	49433	36190	34531	3837	0
2047	18930	52949	53700	55886	18930	39105	49740	36415	34746	3861	0
2048	19046	53275	54031	56230	19046	39346	50047	36639	34960	3884	0
2049	19163	53602	54362	56575	19163	39587	50353	36863	35174	3908	0
2050	19280	53928	54694	56920	19280	39828	50660	37088	35389	3932	0

Table 69-Trip Assignment – T.Scenario 2

	North East Road - AADT [veh/day]				Lower North East Road - AADT [veh/day]				Modbury Corridor Patronage [passengers/day]		
Year	3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422	Former users	Diverted Users (DU)	New Diverted Users (NDU)
1990	9457	26452	26827	27919	9457	19536	24849	18192	20800	2000	0
1991	9504	26585	26963	28060	9504	19634	24974	18284	21029	2337	0
1992	9588	26819	27200	28307	9588	19807	25194	18444	21260	2362	0
1993	9851	27554	27945	29082	9851	20350	25884	18950	21494	2388	0
1994	10018	28022	28419	29576	10018	20695	26323	19271	21730	2414	0
1995	10436	29191	29605	30810	10436	21558	27421	20075	21969	2441	0
1996	10782	30159	30587	31832	10782	22274	28331	20741	22211	2468	0
1997	10890	30460	30892	32149	10890	22496	28614	20948	22455	2495	0
1998	11355	31762	32213	33524	11355	23458	29837	21844	22702	2522	0
1999	11499	32163	32619	33947	11499	23753	30214	22119	22952	2550	0
2000	11725	32798	33263	34617	11725	24222	30810	22556	23205	2578	0
2001	11725	32798	33263	34617	11725	24222	30810	22556	23460	2607	0
2002	12000	33566	34042	35428	12000	24789	31532	23084	23718	2635	0

2003	12358	34568	35058	36485	12358	25529	32473	23773	23979	2664	0
2004	12728	35603	36108	37578	12728	26294	33445	24485	24243	2694	0
2005	13063	36538	37057	38565	13063	26985	34324	25128	24509	2723	0
2006	13266	37106	37633	39164	13266	27404	34857	25519	24779	2753	0
2007	13469	37674	38208	39764	13469	27823	35391	25909	25051	2783	0
2008	13648	38175	38717	40292	13648	28193	35861	26254	25327	2814	0
2009	13827	38676	39225	40821	13827	28563	36332	26599	25606	2845	0
2010	14018	39210	39767	41385	14018	28958	36834	26966	25887	2876	0
2011	14173	39644	40207	41843	14173	29279	37242	27265	26172	2908	0
2012	14340	40112	40681	42337	14340	29624	37681	27586	26460	2940	0
2013	14484	40513	41088	42760	14484	29920	38058	27862	26751	2972	0
2014	14627	40914	41494	43183	14627	30216	38434	28137	27045	3005	0
2015	14770	41314	41901	43606	14770	30512	38811	28413	27343	3038	0
2016	14913	41715	42307	44029	14913	30808	39187	28689	27644	3072	0
2017	15069	42149	42747	44487	15069	31129	39595	28987	27800	3089	0
2018	15200	42517	43120	44875	15200	31400	39940	29240	27900	3100	0
2019	15331	42884	43493	45263	15331	31671	40285	29493	28141	3127	0
2020	15458	43239	43853	45638	15458	31934	40619	29737	28374	3153	0
2021	15644	43758	44379	46186	15644	32317	41106	30094	28715	3191	0
2022	15832	44283	44912	46740	15832	32705	41600	30455	29059	3229	0
2023	16022	44815	45451	47301	16022	33097	42099	30821	29408	3268	0
2024	16214	45353	45996	47868	16214	33494	42604	31190	29761	3307	0
2025	16408	45897	46548	48443	16408	33896	43115	31565	30118	3346	0
2026	16605	46448	47107	49024	16605	34303	43633	31943	30480	3387	0
2027	16805	47005	47672	49612	16805	34715	44156	32327	30845	3427	0
2028	17006	47569	48244	50208	17006	35131	44686	32715	31215	3468	0
2029	17210	48140	48823	50810	17210	35553	45222	33107	31590	3510	0
2030	17417	48718	49409	51420	17417	35980	45765	33505	31969	3552	0
2031	17626	49302	50002	52037	17626	36411	46314	33907	32353	3595	0
2032	17837	49894	50602	52661	17837	36848	46870	34313	32741	3638	0
2033	18051	50492	51209	53293	18051	37290	47432	34725	33134	3682	0
2034	18268	51098	51824	53933	18268	37738	48002	35142	33531	3726	0
2035	18487	51712	52445	54580	18487	38191	48578	35564	33934	3770	0
2036	18709	52332	53075	55235	18709	38649	49161	35990	34341	3816	0
2037	18934	52960	53712	55898	18934	39113	49751	36422	34753	3861	0
2038	19161	53596	54356	56568	19161	39582	50348	36859	35170	3908	0
2039	19391	54239	55008	57247	19391	40057	50952	37302	35592	3955	0
2040	19623	54890	55669	57934	19623	40538	51563	37749	36019	4002	0
2041	19859	55548	56337	58629	19859	41024	52182	38202	36452	4050	0
2042	20097	56215	57013	59333	20097	41517	52808	38661	36889	4099	0
2043	20338	56889	57697	60045	20338	42015	53442	39125	37332	4148	0
2044	20582	57572	58389	60766	20582	42519	54083	39594	37780	4198	0
2045	20829	58263	59090	61495	20829	43029	54732	40069	38233	4248	0
2046	21079	58962	59799	62233	21079	43546	55389	40550	38692	4299	0
2047	21332	59670	60516	62980	21332	44068	56054	41037	39156	4351	0
2048	21588	60386	61243	63735	21588	44597	56726	41529	39626	4403	0

2049	21847	61110	61978	64500	21847	45132	57407	42027	40101	4456	0
2050	22110	61844	62721	65274	22110	45674	58096	42532	40583	4509	0

Table 70-Trip Assignment – T.Scenario 3

	North East Road - AADT [veh/day]				Lower North East Road - AADT [veh/day]				Modbury Corridor Patronage [passengers/day]		
Year	3020-74	74-282	282-206	206-498	3020-74	74-77	77-265	265-422	Former users	Diverted Users (DU)	New Diverted Users (NDU)
1990	9457	26452	26827	27919	9457	19536	24849	18192	20800	2000	0
1991	9504	26585	26963	28060	9504	19634	24974	18284	21029	2337	0
1992	9588	26819	27200	28307	9588	19807	25194	18444	21260	2362	0
1993	9851	27554	27945	29082	9851	20350	25884	18950	21494	2388	0
1994	10018	28022	28419	29576	10018	20695	26323	19271	21730	2414	0
1995	10436	29191	29605	30810	10436	21558	27421	20075	21969	2441	0
1996	10782	30159	30587	31832	10782	22274	28331	20741	22211	2468	0
1997	10890	30460	30892	32149	10890	22496	28614	20948	22455	2495	0
1998	11355	31762	32213	33524	11355	23458	29837	21844	22702	2522	0
1999	11499	32163	32619	33947	11499	23753	30214	22119	22952	2550	0
2000	11725	32798	33263	34617	11725	24222	30810	22556	23205	2578	0
2001	11725	32798	33263	34617	11725	24222	30810	22556	23460	2607	0
2002	12000	33566	34042	35428	12000	24789	31532	23084	23718	2635	0
2003	12358	34568	35058	36485	12358	25529	32473	23773	23979	2664	0
2004	12728	35603	36108	37578	12728	26294	33445	24485	24243	2694	0
2005	13063	36538	37057	38565	13063	26985	34324	25128	24509	2723	0
2006	13266	37106	37633	39164	13266	27404	34857	25519	24779	2753	0
2007	13469	37674	38208	39764	13469	27823	35391	25909	25051	2783	0
2008	13648	38175	38717	40292	13648	28193	35861	26254	25327	2814	0
2009	13827	38676	39225	40821	13827	28563	36332	26599	25606	2845	0
2010	14018	39210	39767	41385	14018	28958	36834	26966	25887	2876	0
2011	14173	39644	40207	41843	14173	29279	37242	27265	26172	2908	0
2012	14340	40112	40681	42337	14340	29624	37681	27586	26460	2940	0
2013	14484	40513	41088	42760	14484	29920	38058	27862	26751	2972	0
2014	14627	40914	41494	43183	14627	30216	38434	28137	27045	3005	0
2015	14770	41314	41901	43606	14770	30512	38811	28413	27343	3038	0
2016	14913	41715	42307	44029	14913	30808	39187	28689	27644	3072	0
2017	15069	42149	42747	44487	15069	31129	39595	28987	27800	3089	0
2018	15200	42517	43120	44875	15200	31400	39940	29240	27900	3100	0
2019	15331	42884	43493	45263	15331	31671	40285	29493	28141	3127	0
2020	15463	43251	43865	45651	15463	31943	40630	29745	28382	3154	3154
2021	15772	44116	44743	46564	15772	32582	41443	30340	28950	3217	3217
2022	16087	44999	45637	47495	16087	33233	42272	30947	29529	3281	3281
2023	16409	45899	46550	48445	16409	33898	43117	31566	30119	3347	3347

2024	16737	46817	47481	49414	16737	34576	43979	32197	30722	3414	3414
2025	17072	47753	48431	50402	17072	35267	44859	32841	31336	3482	3482
2026	17413	48708	49399	51410	17413	35973	45756	33498	31963	3551	3551
2027	17762	49682	50387	52438	17762	36692	46671	34168	32602	3622	3622
2028	18117	50676	51395	53487	18117	37426	47605	34851	33254	3695	3695
2029	18479	51689	52423	54557	18479	38174	48557	35548	33919	3769	3769
2030	18849	52723	53471	55648	18849	38938	49528	36259	34598	3844	3844
2031	19226	53778	54541	56761	19226	39717	50519	36985	35290	3921	3921
2032	19610	54853	55632	57896	19610	40511	51529	37724	35995	3999	3999
2033	20003	55950	56744	59054	20003	41321	52560	38479	36715	4079	4079
2034	20403	57069	57879	60235	20403	42148	53611	39248	37450	4161	4161
2035	20811	58211	59037	61440	20811	42991	54683	40033	38199	4244	4244
2036	21227	59375	60218	62668	21227	43850	55777	40834	38963	4329	4329
2037	21651	60562	61422	63922	21651	44727	56892	41651	39742	4416	4416
2038	22085	61774	62650	65200	22085	45622	58030	42484	40537	4504	4504
2039	22526	63009	63903	66504	22526	46534	59191	43333	41347	4594	4594
2040	22977	64269	65181	67834	22977	47465	60374	44200	42174	4686	4686
2041	23436	65555	66485	69191	23436	48414	61582	45084	43018	4780	4780
2042	23905	66866	67815	70575	23905	49383	62814	45986	43878	4875	4875
2043	24383	68203	69171	71986	24383	50370	64070	46905	44756	4973	4973
2044	24871	69567	70554	73426	24871	51378	65351	47843	45651	5072	5072
2045	25368	70959	71966	74895	25368	52405	66658	48800	46564	5174	5174
2046	25876	72378	73405	76392	25876	53453	67991	49776	47495	5277	5277
2047	26393	73825	74873	77920	26393	54522	69351	50772	48445	5383	5383
2048	26921	75302	76370	79479	26921	55613	70738	51787	49414	5490	5490
2049	27459	76808	77898	81068	27459	56725	72153	52823	50402	5600	5600
2050	28009	78344	79456	82690	28009	57860	73596	53880	51410	5712	5712