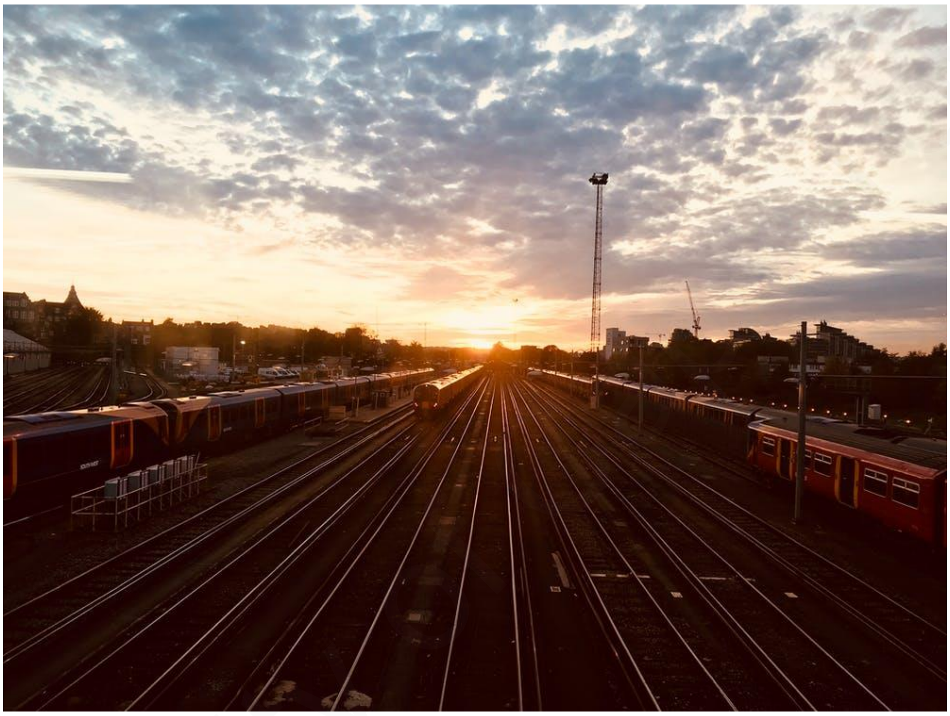
FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING



Evaluating Different Multi-Criteria Decision Methods for the Comparison and Investigation of Public Transport Projects

Thesis presented for the degree of
Master of Science in Engineering in the Department of the Engineering and Built Environment at The University of Cape Town

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ACKNOWLEDGEMENTS

I would like to thank the University of Cape Town and specifically Professor Marianne Vanderschuren for her encouragement, guidance and the wealth of knowledge she provided. I would not have completed this dissertation without their support, especially approving a leave of absence which allowed me to focus on being a new parent.

I am grateful for the financial assistance that UDS Africa has provided, as well as the support and understanding from Mr. Piet van Blerk while I worked full-time and studied part-time to complete this research.

In addition to this, Mr. Pieter Onderwater provided me with industry knowledge relating directly to my research and I am forever grateful for that. I would also like to thank every person who participated in my survey, of which there are too many to mention.

Finally, and most importantly, I would like to thank my parents, husband and friends for encouraging me to complete it and by the grace of the Almighty Allah, I succeeded.

EXECUTIVE SUMMARY

There is a need for affordable, reliable, and safe public transport in South Africa. In Cape Town, the most popular modes of public transport are rail, bus, Bus Rapid Transit (BRT) and minibus taxis. At this stage, the various modes are not integrated and, in some instances, are running in parallel.

Many research papers have focused on comparing the capital costs and benefits of public transport investments and the results often exclude the effects of criteria that are not easily monetised. In South Africa, the Cost-Benefit Analysis (CBA) is often used to evaluate public transport projects, whereas, in this research, Multi-Criteria Decision Analysis (MCDA) methods were investigated and used. The objective of this research was to evaluate the MCDA methods available and establish it as an alternative or supplementary method, or tool, that public transport planners could use when evaluating public transport projects.

In order to test the MCDA methods, Cape Town's existing public transport was used as a case study with each mode assumed to be operating exclusively. Therefore, the five scenarios analysed are: Rail (MetroRail); Bus (Golden Arrow); BRT (MyCiTi) Minibus Taxis, and Integrated Public Transport System (theoretical).

These modes were evaluated against a number of criteria including economic, social, and environmental impacts.

Qualitative methods were focused on, incorporating quantitative methods, in order to gain in-depth insight into public transport management and operations, as well as the costs and benefits involved, both direct and indirect.

Research on public transport practices, locally, nationally, and internationally was performed. From this, alternatives for the case study, as well as the assessment criteria, were established. The research also included investigating multi-criteria analysis methods, ultimately leading to the methods chosen for the analysis. In order to perform the analyses using the alternatives and assessment criteria, the criteria needed to be weighted. The scenarios were analysed using an UNWEIGHTED viewpoint, where each criterion was equally weighted; WEIGHTEDs viewpoint, where each criterion was weighted by key players (specialists) in the public transport discipline; WEIGHTEDp viewpoint, where each criterion was weighted by the general public who have used public transport in Cape Town. As this may lead to differing results, aggregation methods were also included in the research.

As mentioned, the integration of this investigation involves optimising the method in which public transport projects are being evaluated by establishing a multi-criteria analyses method which is reliable, simple, and capable of including a variety of criteria, both monetary, qualitative, and quantitative. A variety of comparative evaluation methods exist. Within this, as mentioned, the popular methods for public transport appraisal are Cost-Benefit Analysis and a variety of Multi-Criteria Decision Analysis methods.

Cost-Benefit Analysis (CBA) is the most used evaluation method for assessing infrastructural investments. In the transport field, it is the basic tool in most countries (Beria *et al*., 2012). The CBA is based on the monetisation and inter-temporal discount. Money is the measure unit used as common numeracy to translate all costs and benefits associated to an investment or a policy. Once all relevant effects of an investment are quantified, the concept of inter-temporal discount is used to translate future costs and benefits to present day by means of a social discount rate. In this way, the future can be compared with the present (Beria *et al*., 2012).

CBA weighs the pros and cons of a project in a rational and systematic process. It inherently requires the creation and evaluation of at least two options, "do it or not", plus it requires an evaluation at several different scales (nothing, minimum and all, as the least requirements) (OECD, 2006; EC, 2008; Ninan, 2008 as cited in Jones *et al*., 2014).

Costs generally associated with a cost-benefit analysis include those related to construction and future maintenance, such as capital, major rehabilitation and annual maintenance costs over the life-cycle of the project. Other considerations include discounting of future costs and benefits, dealing with opportunity costs, inflation, avoidance of double counting, avoidance of sunk costs, dealing with joint costs and dealing with the sensitivity analysis (Kentucky Transportation Center, 2016). The limitations often associated with CBA includes omitting costs or key benefits, as well as measuring factors like travel time savings and safety improvements, which are not easily monetised (Kentucky Transportation Center, 2016).

In an attempt to mitigate the weaknesses of the CBA, Multi-Criteria Decision Analysis (MCDA) methods were investigated. Generally speaking, a multiple criteria decision problem is a scenario in which having defined a set of actions/solutions (Do nothing / Upgrade Rail / Additional buses etc.) and a consistent family of criteria (Cost / Accessibility / Safety etc.), the Decision Maker (DM) tends to determine the best subset of actions and solutions according to the criteria (choice problem), divide the solutions into subsets representing specific classes of solutions according to the concrete classification rules (sorting problem) or rank the actions and solutions from best to worst, according to the criteria (ranking problem) (Zak, 2010).

As previously mentioned, there are many MCDA methods available, Macharis & Bernardini (2015) performed an investigation to establish the most commonly used methods used for transport project analysis. The top three most popular methods are AHP/ANP (Analytic Hierarchy/Network Process) – often used in combination with another method, such as the Evaluation of Mixed Data method (EVAMIX), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and Fuzzy Set – often used as a part another method, such as the Simple Additive Weighting Method (SAW, also known as Weighted Sum).

The SAW method appeals to the school of thought of unified scores across alternatives, applying weighting and sums the result per alternative. The EVAMIX method appeals to the second school of thought and takes it one step further. After the unification of scores, the alternatives are compared pairwise (Vanderschuren & Frieslaar, 2008).

In order to compare the outcomes of different methods without the use of specialised software, to make the method accessible, the SAW method and EVAMIX method was used in conjunction with the AHP method, therefore, appealing to both schools of thought.

The AHP method, as developed by Saaty (1980) is a helpful tool for managing qualitative and quantitative criteria involved in decision-making. As stated in the name, it is based on a hierarchical structure (Taherdoost, 2017). The AHP method also develops a linear additive model, but in its standard format, uses procedures for deriving weights and the scores achieved by alternatives which are based, respectively, on pair-wise comparisons between criteria and / or options (Department of Communities and Local Government, 2009). The fundamental input to the AHP method is the decision makers' answers to a series of questions in the general form, 'How important is criterion *A* relative to criterion *B*?' These pair-wise comparisons can be used to establish the weights for criteria and the performance scores for the options on the different criteria (Department of Communities and Local Government, 2009).

The SAW method, also known as weighted linear combination, weighted summation or scoring methods is a simple and often used multi attribute decision technique. The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision maker, followed by summing of the products for all criteria. The advantage of the method is that it is a proportional linear transformation of the raw data which means the relative order of magnitude of the standardised scores remains equal (Afshari *et al*., 2010)

The EVAMIX method was first introduced by Voogd (1982, 1983) and developed by Nijkamp *et al*. (1990), and Martel and Matarazzo (2005) as cited in Tuş Işık & Aytaç Adalı, (2016). A key component of the method is that it includes and combines both ordinal and cardinal, beneficial and non-beneficial data within the same evaluation matrix, hence the name. The EVAMIX method makes different computations to the data in the evaluation matrix depending on whether it is ordinal or cardinal (Hajkowicz & Higgins, 2008, as cited in Tuş Işık & Aytaç Adalı, 2016). The EVAMIX is a simple decision support tool, it requires pairwise comparison of alternatives, for each pair of alternatives, a dominance score for the ordinal and cardinal criteria are calculated. Then these dominance scores are combined into an overall dominance score of each alternative (Hinloopen *et al.*, 2004, as cited in Tuş Işık & Aytaç Adalı, 2016). Finally, the alternatives are ranked based on the appraisal scores (Chatterjee & Chakraborty, 2013, as cited in Tuş Işık & Aytaç Adalı, 2016).

The two chosen MCDA methods rank the alternatives, however the results of these rankings may not be the same, because of the different assumptions made in each method as well as the difference in criteria weights between the weighted and unweighted analyses. In this case, the aggregation of the methods may be needed. In this paper, it is proposed that the Borda and Copeland methods are used, as well as the Average Ranking Procedure. The Average Ranking Procedure ranks the alternatives by their mean values as opposed to the Borda and Copeland Method which rank alternatives by voting (Cheng & Saskatchewen, 2000).

As mentioned, there are many ways that public transport projects are evaluated and part of the reason that a structured methodology is not used, is due to the complex nature of public transport. The potential impacts are directly related to the range (e.g., economic, financial, environmental, social, direct/indirect) and affected groups (users, non-users, as well as government and private operators) (Ferreira & Lake, 2002). For the sake of this thesis, a multi-actor multi-criteria analysis was adopted and the three views were analysed (specialist, academic and transport users).

Using the existing public transport in Cape Town as a case study, the following scenarios were analysed: Existing rail (MetroRail); Existing bus service (Golden Arrow); Existing BRT service (MyCiTi); Existing minibus taxi service and Theoretical integrated public transport system.

It should be noted that for the theoretical integrated transport system, it was assumed that the existing rail, BRT and bus service continued operating and the minibus taxis would operate as feeders to the rest of the system. The services would not operate in parallel. In addition to this, it was also assumed that the BRT system would not expand and instead the funds available would be used to upgrade the existing public transportation along the proposed routes.

The above scenarios were evaluated against a set of criteria. To establish the criteria, the most important criteria were identified by evaluating official statements and government documents to establish what the focus is regarding public transport in South Africa. The criteria were as follows: Cost, Land-Use, Affordability for Users, Accessibility, Estimated Speed, Convenience & Reliability, Environmental Effects, and Safety & Security.

Two methods of MCDA were used with three alternate weightings as previously described, specialist, general public and academic (unbiased).

The AHP method used to establish weightings was simple to use for both the planners/engineers and the general public, as the consistency ratio was under 10% it can, therefore, be concluded that the general public were consistent in their answers thereby understanding the questions and the survey method.

The general public rated 'Accessibility' as the top criteria, whereas the specialists in the private sector and public sector agreed that 'Safety & Security' is the top criteria, which is the second most important criteria to the general public. Tied with 'Safety & Security' for the second most important criteria, the general public also voted for 'Affordability', the private sector specialists agreed, whereas the public sector rated 'Accessibility' as the second most important criteria. In third place, the general public, as well as the specialists in the public sector agreed that 'Cost' is important, whereas the private sector rated 'Accessibility' as the third most important criteria. While the three perspectives differed in ranking, it can be seen that the top four criteria across the board, in no particular order were 'Accessibility', 'Affordability', 'Safety & Security' and 'Cost'.

On the other end of the scale, the lowest weighted criteria were seen to be 'Speed' for the general public and 'Environmental' for engineers in both the public and private sector. The engineers in both the public and private sector agree that 'Speed' is the second least important criteria and conversely, the general public has 'Environmental' listed as the second least important criteria. All three perspectives agree that 'Convenience & Reliability' was the third least important criteria. Therefore, it can be seen that the bottom three criteria, in no particular order were 'Speed', 'Environmental' and 'Convenience & Reliability'.

The SAW method using the specialist weighting (public and private combined) and the general public weighting, resulted in the same conclusion. The theoretical integrated transport system was the best choice, and the BRT system was considered the least favourable. The academic perspective resulted in minibus taxis being the best choice and the worst choice coincided with the specialist and general public perspective, i.e. BRT.

The EVAMIX method results differ slightly between the three perspectives, however, all three agreed that the theoretical integrated transport system was the best alternative. The specialist perspective resulted in the trains being the worst option and the general public and academic perspective resulted in the BRT being the least favourable option.

The results were aggregated using three aggregation methods. These methods resulted in the same three rankings with the theoretical integrated system being the best option for investment and the BRT being least desirable option.

It should be noted that this evaluation was based on a theoretical approach to the integrated transport system and once the system is designed, further evaluation using accurate data, should be performed. This may change the outcome.

In conclusion, both methods of MCDA were implemented with feasible results and, therefore, both methods of MCDA are easily applicable to the evaluation of public transport projects.

It is recommended that, as far as possible, primary data be collected when implementing public transport evaluations. It is also recommended to evaluate public transport projects over the lifecycle of the chosen project. Generally, public transport projects are evaluated by or by the order of the City of Cape Town or Western Cape Government and should this be the case, access to more accurate data should be achievable. It is further recommended that should an integrated transport system be considered, the analysis is re-evaluated with the detailed design of the integrated transport system which would provide more precise data and may change the results.

List of Abbreviations

AHP – Analytic Hierarchy Process

AVP – Average Ranking Procedure

BRT – Bus-Rapid Transport

CBA – Cost-Benefit Analysis

CoCT – City of Cape Town

DM – Decision Makers

EVAMIX – Evaluation of Mixed Data

MAMCA – Multi-Actor Multi-Criteria Analysis

MCDA – Multi-Criteria Decision Analysis

POV – Point of View

SANTACO – South African National Taxi Council

SATC – South African Transport Conference

SAW – Simple Additive Weighting

TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution

UITP – International Association of Public Transport

VOC – Vehicle Operating Cost

VOT – Value of Time

WCG – Western Cape Government

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1 INRODUCTION

1.1 Background to Study

There is a need for affordable, reliable, and safe public transport in South Africa. In Cape Town, the most popular modes of public transport are rail, bus, Bus Rapid Transit (BRT) and minibus taxis. At this stage, the various modes are not integrated and, in some instances, are running in parallel.

A significant portion of research papers have focused on comparing the capital costs and benefits of public transport investments and the results often exclude the effects of criteria that are not easily monetised. In South Africa, the Cost-Benefit Analysis (CBA) is often used to evaluate public transport projects, whereas, in this research, Multi-Criteria Decision Analysis (MCDA) methods are investigated and used. The main objective of this research was to investigate and evaluate the MCDA methods available and establish it as an alternative or supplementary method for the currently used methods in the City of Cape Town, that public transport planners could use when evaluating public transport projects.

The costs often associated with cost-benefit analyses include capital costs, construction time, operation, maintenance costs, as well as other costs and processes, up to and including decommission. The benefits are usually measured in travel time savings and safety (reduction of crashes).

While multi-criteria decision analyses often have 'cost' as a heavily weighted criteria, other non-monetised criteria are considered, such as accessibility, reliability, safety, travel time, environmental effects, etc. The lesser researched effects of public transport, such as the effect of property prices and job creation can be evaluated using a multi-criteria decision analysis should the project lend itself to that.

1.2 Problems to be Investigated

In order to test the MCDA methods, Cape Town's existing public transport was used as a case study. In addition to the four existing modes running exclusively, a theoretical fifth mode was included, which considers the integration of the existing public transport modes.

Therefore, the five scenarios analysed are:

1. Rail (MetroRail),
2. Bus (Golden Arrow),
3. BRT (MyCiTi),
4. Minibus Taxis, and
5. Integrated Public Transport System (theoretical).

The criteria included in this investigation (in no particular order):

1. Cost,
2. Land-Use and Integration,

3. Affordability for Users,
4. Accessibility,
5. Estimated Speed,
6. Convenience & Reliability,
7. Environmental Effects, and
8. Safety & Security.

1.3 Purposes of the Investigation

“Good public transport systems are 'purchasing' urban economic efficiency, not just transport efficiency” (Marsay, 2017).

Currently, there is little research to be found which compares different methods of multi-criteria decision analyses for various modes of public transport. Especially, in Cape Town where the public transport landscape and the geographical layout of the city differs to other cities around the world. The purpose of this investigation was to provide an analysis tool to assist transport planners working on bettering the existing public transport, as well as assessing the efficiency of proposed public transport projects before introducing new modes/upgrading the existing modes available.

This research aimed to establish which method of analysis and mode (or combination of modes) of public transport provided the highest levels of service and positive effects for the lowest overall costs. The research also aimed to provide a simple guide to the use of multi-criteria decision methods in public transport planning including the strengths and weaknesses of the multi-criteria decision methods available.

1.3.1 Research Questions

1. What are the most common methods of MCDA currently being used for public transport evaluation?
2. How did the opinion of the general public differ from that of engineers and government employees regarding the importance of criteria?
3. How do the results differ between methods of MCDA?
4. How do the results differ for different levels of aggregation?
5. What time period should be evaluated in the implementation of public transport projects?

1.4 Major Assumptions Made

Various authorities were contacted in order to obtain the overall costs involved in public transport. However, certain assumptions regarding cost were made as detailed costs were not generally available across the existing public transport modes in Cape Town. As will be discussed, the existing public transport modes are operated and controlled by different authorities and each authority has a different approach to calculating and presenting their costs.

Scenario 5: Integrated Public Transport System was, as mentioned, theoretical and therefore, in order to evaluate it without entering into detailed design, a number of assumptions were made and are listed further below.

In order to evaluate each mode of public transport in Cape Town in each scenario evaluated; it was assumed that the subject mode of public transport was the main mode. This assisted in the evaluation of the efficiency of the mode, regardless of its competitors. Assumptions were also made in order to estimate the capture area around each mode's station. This is discussed further in Section 2: Methodology.

1.5 Structure of the Thesis

The thesis begins with Chapter 2: Methodology, outlining the research process of both the evaluation methods used (Section 2.1 and 2.2), as well as other key literature surrounding the evaluation of public transport projects (Section 2.3). The methodology also outlines the scenarios which were evaluated (Section 2.4 to 2.6).

Chapter 3: Literature Review follows the methodology. The literature review covers the different evaluation methods (Cost-Benefit Analysis and Multi-Criteria Decision Methods) that could be applied to public transport decision making specifically, as well as which methods of multi-criteria analyses were used in this case study (Section 3.1). The literature review covers methods in which the criteria associated with public transport projects, could be quantified and evaluated. The literature review also outlines the criteria most frequently used in public transport project evaluation (Section 3.2). And finally, the review touches on the direct and indirect costs and benefits often associated with different forms of public transport (Section 3.3).

Thereafter, Cape Town as a case study was investigated in Chapter 4: Case Study. The analysis was performed using the different methods of multi-criteria analyses discussed (Section 4.1 to 4.4).

In Chapter 5: Analysis and Results, five scenarios were evaluated using the identified methods, both weighted using weights obtained through stakeholders and unweighted assuming each criterion were of equal priority. Thereafter, the results are discussed in Chapter 6: Discussion.

Finally, the conclusions are listed, and recommendations made for further research in Chapter 7: Conclusions & Recommendations.

2 METHODOLOGY

In this chapter, qualitative methods were focused on, incorporating quantitative methods, in order to gain in-depth insight into public transport management and operations, as well as the costs and benefits involved, both direct and indirect.

Figure 1 shows the method followed in this research. Each step is discussed further below.

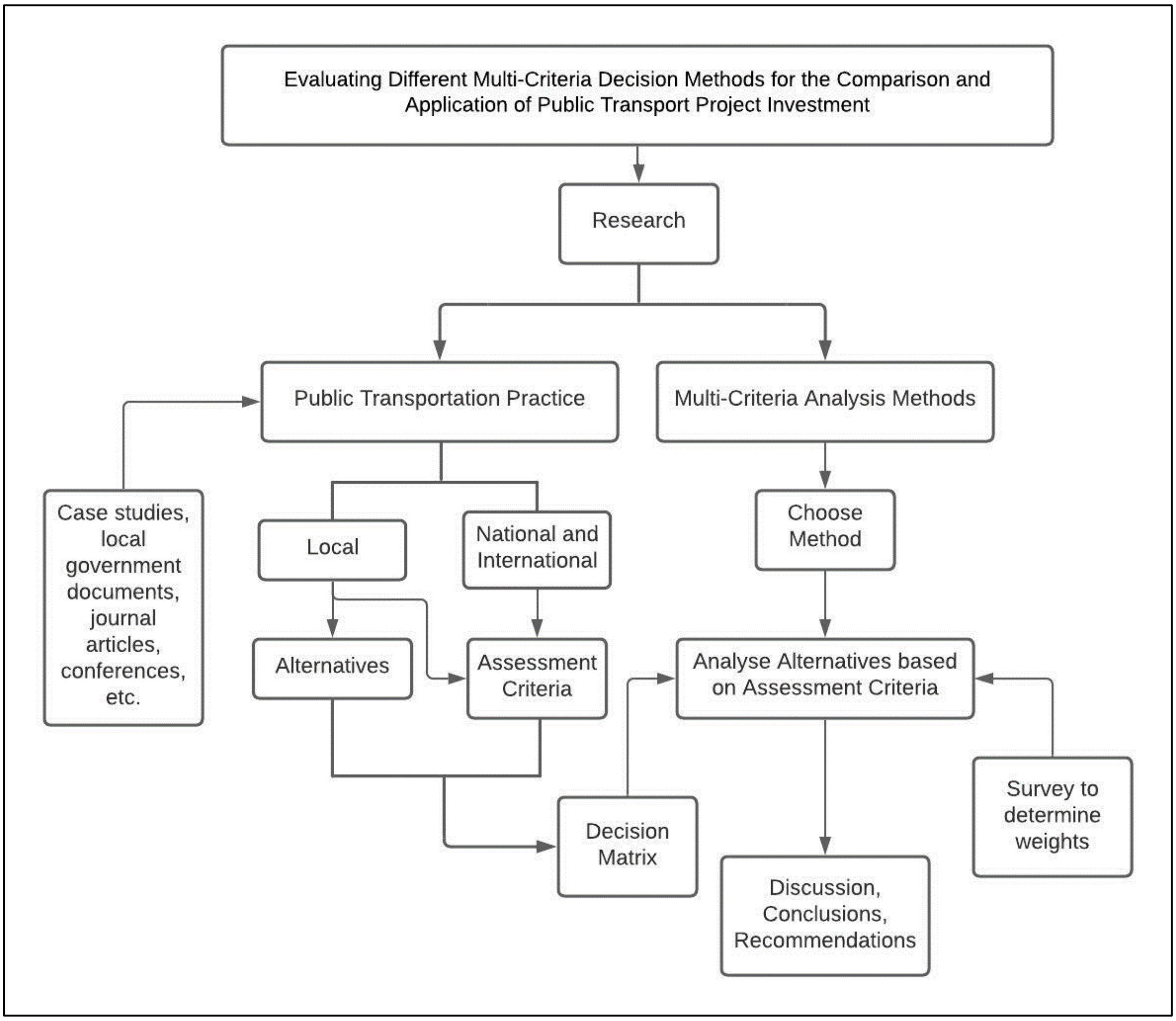

Figure 1: Methodology Flow Chart

2.1 Research Procedure

As shown in Figure 1, research on public transport practice, locally, nationally, and internationally was performed. From this, the alternatives for the case study, as well as the assessment criteria, were established. The research also included multi-criteria analysis methods, ultimately leading to the method chosen for the analysis. Along with the alternatives and assessment criteria previously mentioned, the analysis was performed.

2.1.1 Sources of information

2.1.1.1 City of Cape Town and Western Cape Government

The City of Cape Town (CoCT) and Western Cape Government (WCG) were contacted for information regarding their funding and role in operations of public transport in Cape Town. Official CoCT and WCG documents and statements were investigated to establish the priorities placed on the different criteria available for evaluating public transport. This was done by establishing patterns and trends within the statements to determine where emphasis was placed regarding public transport in Cape Town. The CoCT was also contacted for information regarding the CBA performed before implementing their BRT service, known as the MyCiTi.

2.1.1.2 Transport Conferences and Research Associations

The South African Transport Conferences (SATC) was used for information regarding transport and public transport in South Africa. Conference papers and other related documents are available from the year 2000 onwards which equates to more than 1 500 articles and presentations. The investigation focused on the documents related to public transport and network planning.

Similarly, other relevant international transport conferences were referred to, in order to gain insight into usage patterns in other cities with different demographics and different public transport systems. The International Association of Public Transport (UITP) was used in order to gain knowledge relating to the use of public transport internationally.

The World Resources Institute contains a wide range of information relating to public transport, as well as public transport operations, management and legislation involved. The knowledge gained from The World Resources Institute assisted with obtaining sources with research into the costs and politics associated with public transport.

2.1.1.3 Industry

Civil and transport engineering companies who have worked on public transport projects were contacted. HHO Consulting Engineers (Pty) Ltd and SMEC South Africa have both, been involved in the design and construction of the MyCiTi bus service. These companies would have access to design criteria, construction time, construction cost, design cost, and other traffic analyses. The individual modes of public transport were investigated by contacting each industry, such as Golden Arrow Buses, Metrorail, South African National Taxi Council (SANTACO) and MyCiTi.

2.1.1.4 Other sources

Other sources include publicly accessible data, such as the National Household Travel Survey, other research papers and dissertations accessible both online and through the University of Cape Town's library.

2.2 Multi-Criteria Decision Analysis Methods

2.2.1 Analyses Methods

A multitude of analysis methods are available for comparative project evaluation, however, evaluation methods commonly used in public transport appraisal was focused on – both internationally and locally. The two common methods used in public transport appraisal are, cost-benefit analyses and multi-criteria decision analyses. However, within both methods there exists a variety of ways for them to be implemented, with the possibility of each of them yielding different outcomes.

Once an evaluation method has been established, the evaluation perspective needs to be established. In public transport project evaluation, projects are often evaluated from the perspective of the government, the operators, the users, or other investors who often have opposing viewpoints. This affects the weighting of the criteria, which is discussed further on. Therefore, an emphasis was placed on the choice and justification of the analysis methods used, as well as the perspectives included.

2.3 Scenarios Analysed

Once the evaluation methods have been established. The following five scenarios in Cape Town were analysed.

1. Existing Rail (MetroRail)
2. Existing Bus (Golden Arrow),
3. Existing BRT (MyCiTi),
4. Existing Minibus Taxis, and
5. Theoretical Integrated Public Transport System.

Each scenario was evaluated with the assumption that the subject public transport mode being evaluated is the primary mode of public transport available as it currently stands, aside from Scenario 5, which was theoretical. The services would not run in parallel.

However, it has been acknowledged that other assumptions were made in order to build a realistic scenario. These assumptions include the catchment area, the mode used to reach the station, as well as any additional infrastructure that was necessary in order to cover the case study area, i.e., the City of Cape Town. Reasonable figures (walking time, parking locations, secondary modes, etc.) were researched as part of the literature review and study.

2.4 Criteria and Weighting Used

In each scenario, the public transport mode was evaluated based on the criteria deemed most important in South Africa. A general list of criteria often used in public transport appraisal is as follows (in no particular order):

Costs including:

- Capital Cost,

- Operational Cost,
- Maintenance Cost, and
- Decommission Cost.

Levels of service:

- Travel Time,
- Volume of passengers transported,
- Comfort and Convenience,
- Safety,
- Security,
- Reliability
- Cost to passenger, and
- Accessibility.

As well as other factors affected:

- Environmental effects,
- Employment created,
- Construction Time,
- Land-Use and non-motorised transport (NMT) integration and,
- Effect on property prices.

However, as will be discussed, research shows that not all criteria can be considered in a multi-criteria decision analysis as it leads to inconsistent results. In order to filter out the criteria with a higher priority; articles, documents, and statements from the CoCT and WCG were consulted.

Three alternative weighting viewpoints were analysed.

1. UNWEIGHTED: The academic (unbiased) viewpoint, where each criterion will be equally weighted to determine the effect of weighting on the results, and
2. WEIGHTEDs: The specialist viewpoint, where each criterion will be weighted by key players in the public transport discipline – this includes civil and transport engineers in industry, Western Cape Government and City of Cape Town employees working in their respective transport departments, academics working in traffic and transportation planning, as well as a number of experts outside of traffic engineering, such as environmental practitioners and network planners.
3. WEIGHTEDp: The general public viewpoint from people who have used public transport in Cape Town.

2.5 Case Study Evaluation, Results and Analyses

The following evaluations were performed: two different evaluation analyses methods performed on the five listed scenarios. While using the determined criteria, from both the academic (unbiased), specialist and public weighting viewpoints for Cape Town public transport services. Thereafter, the results were aggregated in order to determine one result and to compare it to the individual results obtained.

3 LITERATURE REVIEW

This investigation involved optimising the method in which public transport projects are being evaluated by establishing a multi-criteria analyses method which is reliable, simple, and capable of including a variety of criteria, both monetary, qualitative, and quantitative. Therefore, the literature review intended to document and summarise the existing literature that would contribute to the topic.

At this stage, the investigation is broad and, therefore, the literature review covers a wide area of topics surrounding evaluation methods, (i.e. Cost-Benefit Analysis and Multi-Criteria Decision Analysis methods), the costs and benefits of public transport, based on the factors previously mentioned, namely, Costs (capital, operational, maintenance, decommissioning and construction time), Levels of Service (travel time, volume of passengers transported, convenience, reliability, safety, security, cost to passenger and accessibility), as well as other factors affected, such as employment creation, environmental effects and the effect on property prices.

3.1 Evaluation Methods

A variety of comparative evaluation methods exist. Within this, the popular methods for public transport appraisal are Cost-Benefit Analysis and a variety of Multi-Criteria Decision Analysis methods. The following research will identify the different methods commonly used, as well as the strengths and weaknesses discovered.

3.1.1 Cost-Benefit Analysis Method

Cost-Benefit Analysis (CBA) also known as Benefit-Cost Analysis (BCA) is the most used evaluation method for assessing infrastructural investments. In the transport field, it is the basic tool in most countries (Beria *et al.*, 2012). As an example, The Transportation Investments Generating Economic Recovery (TIGER) Discretionary Grants (United States) require that proposers submit a CBA along with a project proposal. (Kentucky Transportation Center, 2016)

Key questions a CBA can help address are (Lawrence *et al.*, 2014 as cited in Kentucky Transportation Center, 2016):

1. Should a project be undertaken?
2. When should a project be undertaken?
3. Which projects and/or project alternatives should be funded?
4. Evaluation of project performance

The CBA is based on the monetisation and inter-temporal discount. Money is the measure unit used as common numeracy to translate all costs and benefits associated to an investment or a policy. Once all relevant effects of an investment are quantified, the concept of inter-temporal discount is used to translate future costs and benefits to present day by means of a social discount rate. In this way, the future can be compared with the present (Beria *et al.*, 2012).

CBA weighs the pros and cons of a project or policy in a rational and systematic process. It inherently requires the creation and evaluation of at least two options, "do it or not", plus it requires an evaluation at several different scales (nothing, minimum and all, as the least requirements) (OECD, 2006; EC, 2008; Ninan, 2008 as cited in Jones *et al.*, 2014).

CBA monetises both inputs and outputs and explicitly states economic assumptions so that they are not overlooked or remain implicit (World Bank, 2004 as cited in Jones, Moura, & Domingos, 2014), including externalities, thus integrating economic and environmental considerations into decision making (Beder, 2000 as cited in Jones, Moura, & Domingos, 2014). It also includes the accounting of time through the use of discount rate (Ninan, 2008; Munger, 2000 as cited in Jones, Moura, & Domingos, 2014). Essentially it seeks to enumerate all direct costs and benefits to society of a particular project, assign monetary values, discount them to a net present value and add them to a single number to evaluate the project (Nicke, *et al.*, 2009 as cited in Jones *et al.*, 2014).

Costs generally associated with a cost-benefit analysis include those related to construction and future maintenance, such as capital, major rehabilitation and annual maintenance costs over the life-cycle of the project. Other considerations include discounting of future costs and benefits, dealing with opportunity costs, inflation, avoidance of double counting, avoidance of sunk costs, dealing with joint costs and dealing with the sensitivity analysis (Kentucky Transportation Center, 2016).

The general approach to conducting a CBA is shown below (Guo *et al.*, 2008 as cited in (Kentucky Transportation Center, 2016):

1. Define the base case and the options,
2. Identify the scope of the CBA,
3. Identify investment impacts within the scope,
4. Measure the impacts and convert them into monetary values,
5. Calculate the net present value for the options proposed,
6. Conduct sensitivity and/or risk analyses, and
7. Make funding decisions based on the information gathered.

The net present value is calculated using the following equations (Kentucky Transportation Center, 2016):

$$PV = \frac{B_n}{(1+d)^{(n-o)}} \quad (1)$$

Where: PV = present value
B = benefit (cost)
N = year benefit (cost) is incurred
o = year to which discounting is occurring
d = discount rate

Thereafter,

$$NPV = \sum PV_b - PV_c \qquad (2)$$

Where: PV_b = present value of benefits
PV_c = present value of costs

If the benefits are greater than costs, the NPV is positive. This would suggest a project may be worth investigating further. When project alternatives are being compared, the project with the highest NPV is generally further investigated. However, it should be mentioned that the NPV favours large projects (Bruun & Vanderschuren, 2017), which is not necessarely in the best interest of society at large.

In some cases, the benefit-cost ratio (BCR) is also used. It is applicable if there are funding issues that need to be considered. To calculate BCR, the benefits are discounted in the numerator and the agency investment cost discounted in the denominator. See the equation below:

$$BCR = \frac{\sum PV_b}{\sum PV_c} \qquad (3)$$

If multiple alternatives are being considered, the Incremental Benefit-Cost Ratio (IBCR) can be used. The IBCR compares the change in present value between two alternatives. Alternatives are arranged from least to most expensive and the first round it only compares the first options which are termed the defender and challenger with the challenger being the more expensive alternative. The equation contrasting the projects is shown below:

$$IBCR = \frac{\sum PV_{b,d} - \sum PV_{b,f}}{\sum PV_{c,d} - \sum PV_{c,f}} \qquad (4)$$

Where: IBCR = Incremental Benefit-Cost Ratio

$PV_{b,d}$ = present value of defender benefits
$PV_{b,f}$ = present value of challenger benefits
$PV_{c,d}$ = present value of defender costs
$PV_{c,f}$ = present value of challenger costs

If the IBCR is greater than or equal to 1.0, it means the benefits of the challenger are equal to or greater than its increase in costs. If this is the case, the current challenger becomes the defender to be compared to the next project. If the IBCR is less than 1.0, the current defender is retained and the new challenger is the next alternative on the project list. This continues until all alternatives have been evaluated and the last defender is considered the most economically efficient.

In certain cases, the Internal Rate of Return (IRR) is included in the analysis. IRR is the discount rate that results in the net present value of project cash flow equal to zero, and projects with a high IRR are considered to have greater value. Other factors which are sometimes included are

Payback Period, the amount of time required for the cumulative benefits to equal the cumulative costs (both discounted to present value) and lastly, Cost Effectiveness which compares discounted benefits of alternative projects with the assumption of budgetary constraints (Kentucky Transportation Center, 2016) .

The general method is shown graphically, in Figure 2.

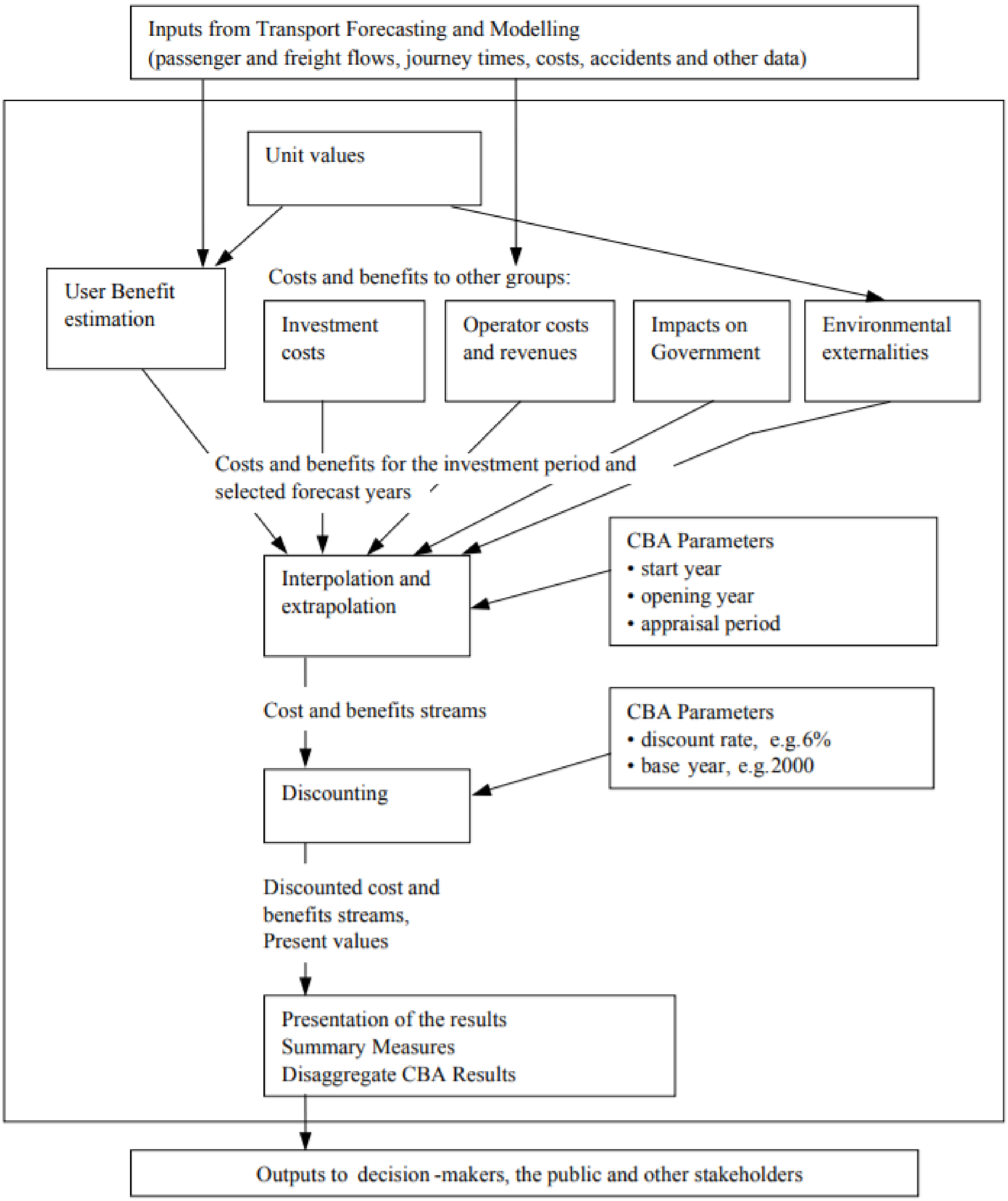

Figure 2: Cost-Benefit Analysis Method in Transportation
Source: Mackie, 2010

The limitations often associated with CBA includes omitting costs or key benefits, as well as measuring factors like travel time savings and safety imporvements, which are not easily monetised (Kentucky Transportation Center, 2016). Traditional CBA also ignores the distribution effects of such decisions, such as how they affect different regions and/or social groups. (Lucas, et al., 2015)

The other weaknesses of CBA are shown in Table 1 below.

Table 1: Major Weaknesses of CBA (Source: (Jones *et al*., 2013)

Factor	Weakness	Sources
Traffic Forecast	Commonly off by 20%-60% (usually overestimated).	Skamris & Flyvbjerg, 1997; Flyvbjerg, Bruzelius, & Rothengatter, 2003; Flyvbjerg, 2005; World Bank, 2005a; Mayer & McGoey-Smith, 2006; van Wee, 2007; Salling & Banister, 2009; Rasouli & Timmermans, 2012
Cost Estimation	Overruns of 50%-100% are not uncommon (usually underestimated).	Skamris & Flyvbjerg, 1997; Flyvbjerg, Bruzelius, & Rothengatter, 2003, Flyvbjerg, Skamris Holm, & Buhl, 2004; Flyvbjerg, 2005; Mayer & McGoey-Smith, 2006; van Wee, 2007; Salling & Banister, 2009; Rasouli & Timmermans, 2012
Discount Rate	Impossible to forecast long-term. Higher rates favor smaller investment or short term benefits.	Farber & Hemmersbaugh, 1993; Weitzman, 1994; Weitzman, 1998; Weitzman, 2001; Florio & Vignetti, 2003; RAILPAG, 2005; Florio, 2006a; Florio, 2006b; EC, 2006
Value of Life	Hard to Determine, no agreement on method or value.	Farber & Hemmersbaugh, 1993; Hanley & Spash, 1993; Gerrod & Willis, 1999; Miller, 2000; Dubgaard, Kallesoe, Petersen, and Ladenburg, 2002; Mrozek & Taylor, 2002; Quinet & Vickerman, 2004; de Blaeij, Florax, Rietveld, & Verhoef, 2007; Bellavance, Dionne, & Lebeau, 2007; Trottenberg & Rivkin, 2011
Value of Time	Complex procedure, no consensus on which variables are relebant and relationships among values.	Bristow & Nellthorp, 2000; Grant-Muller, Mackie, Nellthorp, & Pearman, 2001; World Bank, 2005
Regional Impacts	Does not account for network or crowding out effects.	Rietveld, 1989; EC, 1997; Banister & Berechman, 2000; Sieber, 2001; Vickerman, 2007; Flyvbjerg, Bruzelius, & Rothengatter, 2003, Mairate & Angelini, 2006; Banister, 2007; Coto-Millan, Inglada, & Rey, 2007; van Wee, 2007; ITF, 2011
Local Impacts	Does not account for agglomeration and land use interaction.	Chintz, 1961; van Wee, 2007; Banister, 2007; Martinez, 2010

Equity	Not included in CBA. Monetization not universally accepted.	Mera, 1967; Hewings, 1978; Richardson, 1979; Bateman, Turner, & Bateman, 1993; Masser, Sviden, & Wegener, 1993; de Silva & Tatam, 1996; Banister & Berechman, 2000; Beder, 2000; Bristow & Nellthorp, 2000; Feitelson, 2002; Persky, 2001; Heinzerling & Ackerman, 2002; Annema Koopmans, & van Wee, 2007; Ninan, 2008; Thomopoulos, Grant-Muller, & Tight, 2009; Shi & Wu 2010, Martens, 2011
Environmental Impacts	Difficult to monetize with large uncertainty ranges. LCA is not performed, thus not accounting for impacts from the cosntruction and maintenance of infrastructure.	Culhane, 1987; Buckley, 1991; Button, 1994; EC, 1995; Wood, Dipper, & Jones, 2000; Banister & Berechman 2000; Niemeyer & Spash, 2001; Heinzerling & Ackerman, 2002; Gijsen & van der Brink, 2002; Flyvbjerg, Bruzelius, & Rothengatter, 2003, van Wee, van der Brink, & Nijland, 2003; Laird, Nellthorp, & Mackie, 2005; Chester & Horvath, 2007; van Wee, 2007
Residual Value	Often overlooked. No agreement on methodology.	Lee Jr., 2002; Florio & Vignetti, 2003; RAILPAG, 2005; EC, 2006; IASB, 2006; Edgerton, 2009; Matria, 2012

Examples of the use of CBA in transportation evaluation can be found in Section 9: Appendices.

3.1.2 Multi-Criteria Decision Analysis Methods

Generally speaking, a multiple criteria decision problem is a scenario in which having defined a set of actions/solutions (Do nothing / Upgrade Rail / Additional buses etc.) and a consistent family of criteria (Cost / Accessibility / Safety etc.), the Decision Maker (DM) tends to determine the best subset of actions and solutions according to the criteria (choice problem), divide the solutions into subsets representing specific classes of solutions according to the concrete classification rules (sorting problem) or rank the actions and solutions from best to worst, according to the criteria (ranking problem) (Zak, 2010).

The generally followed process consists of:

1. Recognition of major stakeholders,
2. Analysis of stakeholders' expectations,
3. Definition of criteria,
4. Generating actions / solution scenarios,
5. Evaluation of the scenarios (construction of the evaluation matrix),
6. Definition of stakeholders' preference models,
7. Computational experiments – generation of two final rankings, and
8. Recommendation and final selection of the most satisfactory compromise solution.

The above is shown graphically in Figure 3.

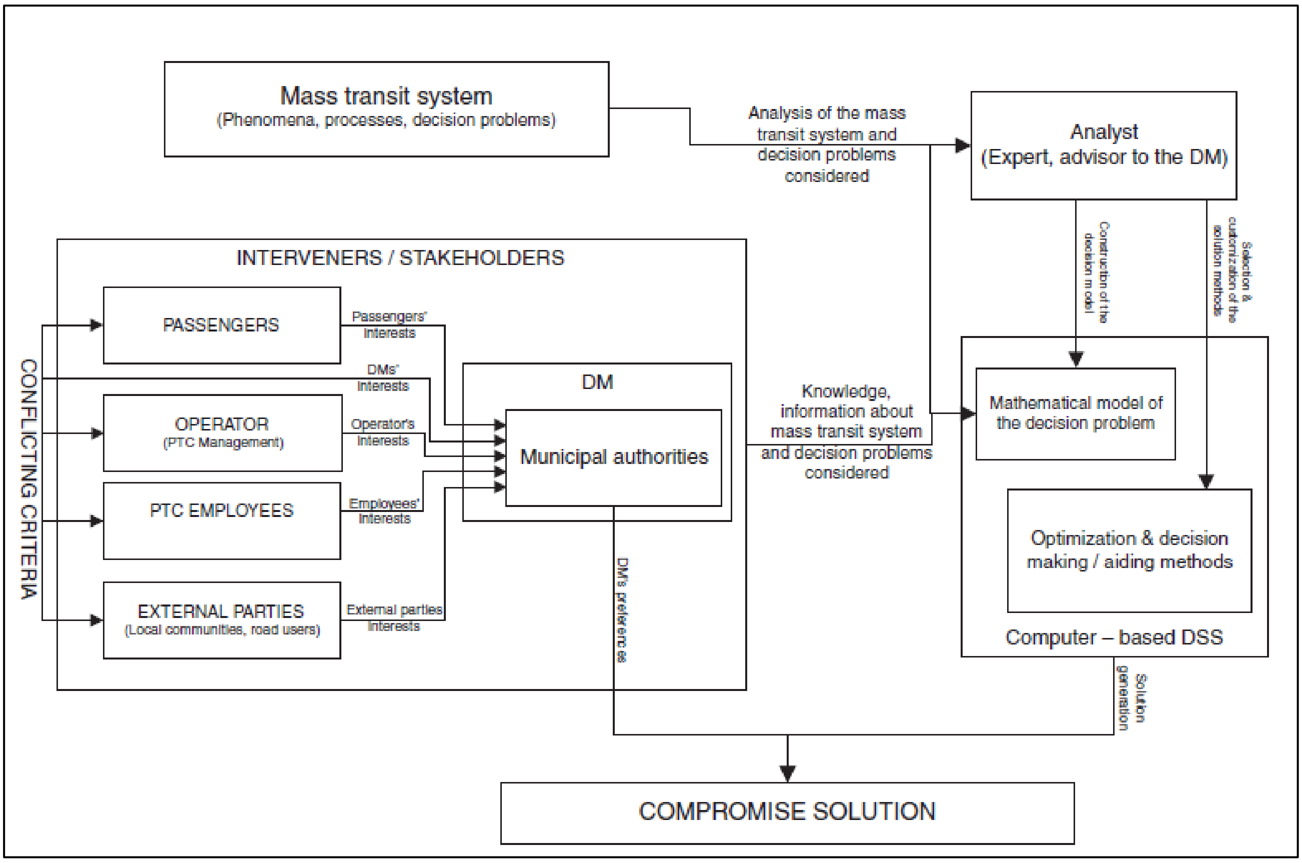

Figure 3: The universal scheme of the multi-criteria decision-making process in mass transit systems
Source: Zak, 2010

As previously mentioned, there are many MCDA methods available, Macharis & Bernardini (2015) performed an investigation to establish the most commonly used methods used for transport project analysis. The results are shown below.

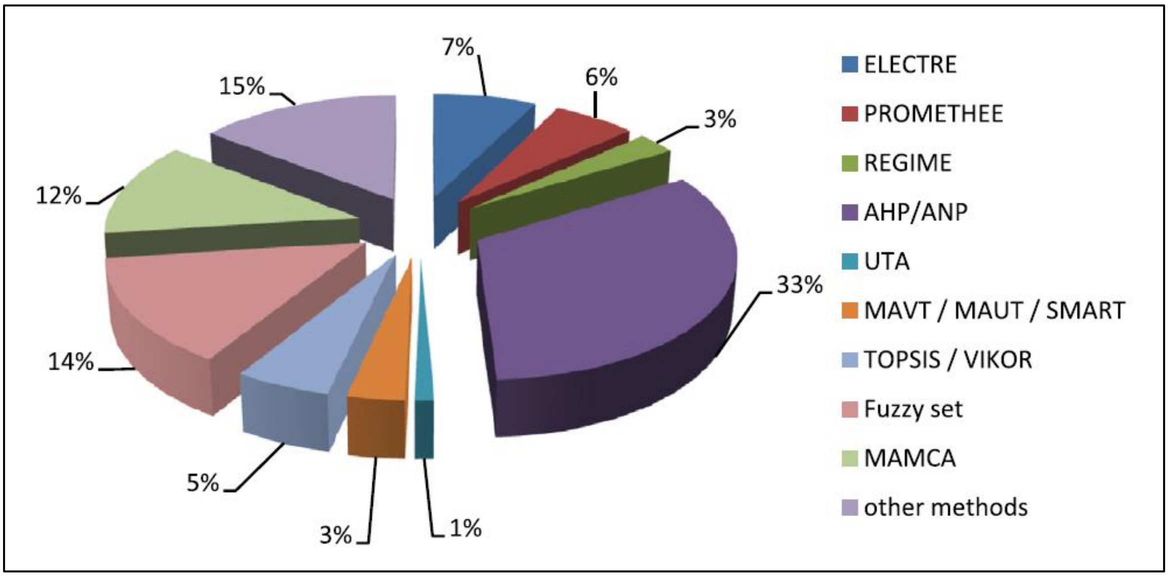

Figure 4: MCDA methods used for transport projects (period: 1985-2012)
Source: Macharis & Bernardini, 2015

As can be seen, the three most popular methods are AHP/ANP (Analytic Hierarchy/Network Process) – often used in combination with another method, such as the Evaluation of Mixed Data method (EVAMIX) – TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and Fuzzy Set; often used as a part another method, such as the Simple Additive Weighting Method (SAW, also known as Weighted Sum).

The SAW method appeals to the school of thought of unified scores across alternatives, applying weighting and summing the result per alternative. The EVAMIX method appeals to the second school of thought, taking it one step further where after the unification of scores, the alternatives are compared pairwise (Vanderschuren & Frieslaar, 2008).

In order to compare the outcomes of different methods without the use of specialised software to increase method accessibility, SAW and EVAMIX methods were used in conjunction with the AHP method, therefore, appealing to both schools of thought.

3.1.2.1 The Analytical Hierarchy Process (AHP Method)

The AHP method, as developed by Saaty (1980) is a helpful tool for managing qualitative and quantitative criteria involved in decision-making. As stated in the name, it is based on a hierarchical structure (Taherdoost, 2017).

The AHP method also develops a linear additive model, but in its standard format, uses procedures for deriving weights and the scores achieved by alternatives which are based, respectively, on pair-wise comparisons between criteria and / or options (Department of Communities and Local Government, 2009). The fundamental input to the AHP method is the decision makers' answers to a series of questions in the general form, 'How important is criterion *A* relative to criterion *B*?' These pair-wise comparisons can be used to establish the weights for criteria and the performance scores for the options on the different criteria (Department of Communities and Local Government, 2009).

A study by Wang and Yang (1998) on the theoretical validity, predictive and perceived performance of three multi-attribute weight measurement methods using: Saaty's AHP and Edward's Simple Multi-Attribute Rating Technique (SMART) compared to Anderson's Functional Measurement (FM) as a theoretical validity standard. The study found that AHP was perceived as an equally valid method to SMART and FM, but in terms of perceived performance, AHP is significantly preferred and perceived as easier to use (Macharis, *et al.*, 2012).

The recommended steps in the AHP process are (Zietsman & Vanderschuren, 2014):

Step 1: Define the decision problem and goal.

Step 2: Structure the hierarchy of the problem and potential solutions from goal to alternatives as shown in the figure below.

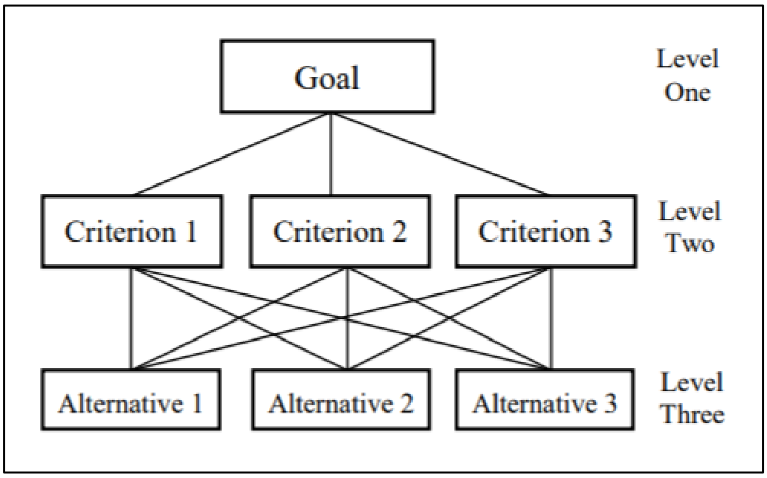

Figure 5: Simple Hierarchial Tree
Source: Taherdoost, 2017

Step 3: Construct *n x n* matrices of pairwise comparison for each element by using the relative scale of importance.

The relative scale of importance is based on Saaty's scale to compare the relative importance of two alternatives. These judgements are then converted into a numerical weight, allowing a local priority in the interval (0,1) to be associated with each criterion (Zietsman & Vanderschuren, 2014). The table below indicates Saaty's nine-point subjective judgement scale.

Table 2: Responses of relative importance based on Saaty's nine-point scale (Source: Berritella *et al*., 2009)

Preference Index Assigned	How important is *A* relative to *B*	Explanation
1	Equally Important	Two criteria contribute equally to the objective.
3	Moderately more important	Experience and judgement slightly favour one criterion over the other.
5	Strongly more important	Experience and judgement strongly favour one criterion over the other.
7	Very strongly more important	A criterion is strongly favoured over the other (its dominance may even be demonstrated in practice).
9	Overwhelmingly more important	The evidence favouring one criterion over the other is the highest possible order of affirmation.
2, 4, 6 and 8 are intermediate values that can be used to represent shades of judgement between the five basic assessments. If *B* is judged to be more important than *A*, the reciprocal relevant index is assigned. That is to say, if *B* is judged to be *x* more important than *A*, the value of 1/*x* would be assigned to *A* relative to *B*.		

Step 4: Compute the eigenvalue and henceforth, the relative weights of the criteria. Berrittella *et al*. (2009) explained the step as follows:

- A judgement matrix is used for prioritising the elements:

$$A = a_{ij}\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & , & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Where a_{ij} represents the pairwise comparison rating between element *i* and element *j* with respect to a higher hierarchical level.

- The priorities of the elements can be estimated by finding the principal eigenvector *w* of the matrix *A*.

$$A\ x\ w = \lambda_{max} w \quad (2)$$

Where λ_{max} is the largest eigenvalue of the matrix *A*.

- Once the local priorities are determined, the final priorities of the alternatives are determined using:

$$S_i = w_i s_{i1} + w_{i2} s_{i2} + \cdots + w_i s_{in} = \sum_{i=1}^{n} w_i s_{ij} \quad (3)$$

Where w_i is the local priority of element *i* and *sij* is the priority with respect to the objective.

Step 5: Conduct the consistency analysis

- The AHP method allows inconsistency in judgment and, consequently provides a method to measure the inconsistency in each set of judgments. This is determined by the Consistency Ratio (CR), defined as (Berrittella, *et al*., 2009):

$$CR = \frac{CI}{RI} \quad (4)$$

Where,

Consistency Index = CI = $CI = \frac{\lambda_{max} - n}{n-1}$ (5)

And RI = Random Consistency Index as shown below:

Matrix size	Random consistency index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Figure 6: Random Consistency Index (Source: Saaty, 1980)

Generally, CR of less than 10% is considered acceptable. Values higher than this warrant judgements (Chu & Kuang-Han Liu, 2001). However, it should be noted that studies have mentioned that the ruling is too absolute, and results should be considered case-by-case (Alonso & Lamata, 2005).

An example of the AHP method being used in transportation evaluation can be found in Section 9: Appendices.

3.1.2.2 Simple Additive Weighting (SAW) Method

The SAW method, also known as weighted linear combination, weighted summation or scoring methods is a simple and is an often used multi attribute decision technique.

The SAW method is widely used, due to its simplicity (Zanakis, 1998 as cited in Keyvan & Cats, 2015). To make all the ratings comparable, the normalisation of the decision matrix is required.

The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision maker, followed by summing of the products for all criteria. The advantage of the method is that it is a proportional linear transformation of the raw data which means the relative order of magnitude of the standardised scores remains equal (Afshari *et al.*, 2010).

The method, as described by Afshari, Mojahed, & Yusuff (2010), is:

Step 1: Implement the AHP method as described above, in order to determine the criteria weights.

Step 2: Construct a decision matrix (*m* x *n*) that includes *m* alternatives and *n* criteria. Calculate the normalised decision matrix for positive criteria:

$$n_{ij} = \frac{r_{ij}}{r*_j} \qquad i = 1, \dots m, \qquad j = 1, \dots n \qquad (6)$$

And for negative criteria:

$$n_{ij} = \frac{r_{minj}}{r_{ij}} \qquad i = 1, \dots m, \qquad j = 1, \dots n \tag{7}$$

Where, $r *_j$ is a maximum number of r in the column of j.

Step 3:

Evaluate each alternative, A_i, using the following formula:

$$A_i = \sum w_j . x_{ij} \tag{8}$$

Where x_{ij} is the score of the ith alternative with respect to the jth criteria and w_j is the weight of the criteria.

The larger the A_i value, the more preferable the alternative.

The method described above, is summarised in the Figure below.

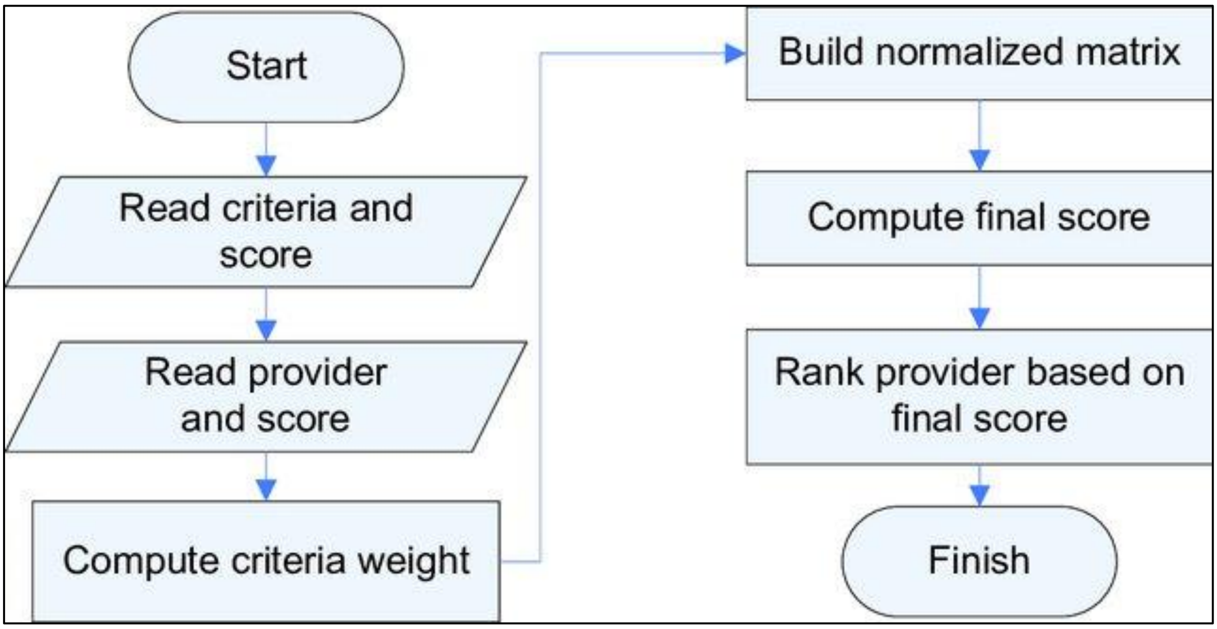

Figure 7: SAW Flowchart
Source: Ciptayani, P & Dewi, K, 2017

3.1.2.3 The Evaluation of Mixed Data (EVAMIX) method

The EVAMIX method was first introduced by Voogd (1982, 1983) and developed by Nijkamp *et al*. (1990), Martel and Matarazzo (2005) cited in Tuş Işık & Aytaç Adalı, (2016).

A key component of the method is that it includes and combines both ordinal and cardinal, beneficial and non-beneficial data within the same evaluation matrix, hence the name. The

EVAMIX method makes different computations to the data in the evaluation matrix depending on whether it is ordinal or cardinal (Hajkowicz & Higgins, 2008, as cited in Tuş Işık & Aytaç Adalı, 2016).

The EVAMIX is a simple decision support tool, it requires pairwise comparison of alternatives, for each pair of alternatives, a dominance score for the ordinal and cardinal criteria are calculated. The dominance scores are then combined into an overall dominance score for each alternative (Hinloopen *et al*., 2004, as cited in Tuş Işık & Aytaç Adalı, 2016). Finally, the alternatives are ranked based on the appraisal scores (Chatterjee & Chakraborty, 2013, as cited in Tuş Işık & Aytaç Adalı, 2016).

The method, as described by Tuş Işık & Aytaç Adalı (2016), is as follows:

Step 1: Criteria are divided into two categories: ordinal and cardinal.

Step 2: The original data is normalised using linear normalisation procedure, using equation (9) for benefical criteria and (10) for non-beneficial criteria.

$$r_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, \quad i = 1, \ldots m \qquad j = 1, \ldots n \tag{9}$$

$$r_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, \quad i = 1, \ldots m \qquad j = 1, \ldots n \tag{10}$$

Step 3: Unique pairs of alternatives are identified and the dominance scores of the *i*th alternative on each orindal and cardinal criterion with respect to other alternatives are calculated. Then, equation (11) and (13) are performed for computing the dominance scores of each alternative pair (i,i') for all the ordinal and cardinal criteria respectively:

$$\alpha_{ii\prime} = \left[\sum_{j\in 0}\left\{w_j sgn(r_{ij} - r_{i'j})\right\}^c\right]^{1/c} \tag{11}$$

$$sgn\left(r_{ij} - r_{i'j}\right) = \begin{cases} +1 & if \quad r_{ij} > r_{i\prime j} \\ 0 & if \quad r_{ij} = r_{i\prime j} \\ -1 & if \quad r_{ij} < r_{i\prime j} \end{cases} \tag{12}$$

$$\gamma_{ii\prime} = \left[\sum_{j\in 0}\left\{w_j (r_{ij} - r_{i'j})\right\}^c\right]^{1/c} \qquad c = 1, 3, 5 \tag{13}$$

In these formulas $\alpha_{ii\prime}$ and $\gamma_{ii\prime}$ are the ordinal and cardinal dominance scores, respectivaly. *O* and *C* are the sets of ordinal and cardinal criteria. w_j is the weight of the *j*th criterion. The weights can be found by any weighting techniques. *c* is a scaling parameter which controls the influences of differences arising from minor criteria. The larger *c* is the lesser of the influences for differences on minor criteria.

Step 4: The standardised dominance scores are calculated because of the different units of the ordinal and cardinal dominance scores. In the literature, there are many approaches to derive standardized dominance scores. Tuş Işık & Aytaç Adalı (2016) used an additive interval method, see equation (14) and (15), for the standardized ordinal dominance score ($\delta_{ii'}$) and standardised cardinal dominance score ($d_{ii'}$).

$$\delta_{ii'} = \frac{\alpha_{ii'} - \alpha^-}{\alpha^+ - \alpha^-} \tag{14}$$

$$d_{ii'} = \frac{\gamma_{ii'} - \gamma^-}{\gamma^+ - \gamma^-} \tag{15}$$

Where, $\alpha^+$and α^- are the highest and lowest ordinal dominance score for the alternative pair (i, i'). $\gamma^+$and γ^- are the highest and lowest cardinal dominance score for the alternative pair (i, i').

Step 5: Calculate the overall dominance score () using the equation below:

$$D_{ii'} = w_O \delta_{ii'} + w_C d_{ii'} \tag{16}$$

Where, w_O is the sum of the weights assigned to the ordinal criteria and w_C is the sum of weights assigned to the cardinal criteria.

Step 6: Lastly, the appraisal score for each alternative is calculated using the equation below:

$$S_i = \left(\sum_{i'} \frac{D_{i'i}}{D_{ii'}}\right)^{-1} \tag{17}$$

As seen in equation (17), the appraisal score of each alternative depends on the overall dominance score of it. The appraisal score of each alternative is used to determine the final ranking of alternatives from best to worst. A higher appraisal score means a better performance of the alternative.

An example of the methods above is described in Section 9: Appendices.

3.1.3 Aggregation Methods

MCDA methods rank the alternatives; however results of these rankings may not be the same because of the different assumptions made in each method as well as the difference in criteria weights between the weighted and unweighted analyses. In this case, the aggregation of the methods may be needed. In this paper, it is proposed that the Borda and Copeland methods are used, as well as the Average Ranking Procedure. The Average Ranking Procedure ranks the alternatives by their mean values as opposed to the Borda and Copeland Method which rank alternatives by voting (Cheng & Saskatchewen, 2000).

3.1.3.1 Borda Method

The Borda method is based on the concept of voting and a majority rule binary relation (Tuş Işık & Aytaç Adalı, 2016). Borda orders the alternatives according to the sum of the ranks they occupy in their profile by assigning the value of one to the last position, two to the second last position and so on (Lamboray, 2007). The alternatives are then ranked from the highest to the lowest score, with higher being preferable.

3.1.3.2 Copeland Method

The Copeland method incorporates pairwise comparison and only the majority winner receives a point. One point is assigned if alternative A outranks alternative B, half a point is assigned if they are tied, and zero points are assigned if alternative B outranks alternative A. The alternatives are then ranked from highest score to lowest score, with higher being preferable (Saari & Merlin, 1996).

3.1.3.3 Average Ranking Procedure

Unlike the other two methods explained, the Average Ranking Procedure ranks the alternatives by their mean values by assigning index values to the results of the MCDA rankings. Therefore, the 1st position will be assigned the number one, the 2nd position will be assigned the number two, and so on. The mean value per alternative is then calculated and these values are used to define a new ranking for the alternatives with higher being preferable (Cheng & Saskatchewen, 2000).

3.1.4 CBA versus MCDA methods

Evaluation (*ex-post* and *ex-ante*) of transportation plans and projects have been carried out in the past, using a variety of methodological frameworks. The methods can be grouped into two major categories: Single criterion (monetary approach) and multi-criteria methods (non-monetary approach). The CBA analysis belongs in the first category and the MCA in the second (Beria *et al*., 2012).

According to Bruun & Vanderschuren (2017) and Zak (2010), public transport projects should be evaluated using performance indicators related to the ‘triple bottom line’, i.e. economic, social and environmental impacts. The often-used CBA involves monetising all costs and benefits relating to a project or policy strategy and examining the ratio of total benefits with respect to total costs, i.e. The benefits-cost ratio (Browne & Ryan, 2011).

Bruun & Vanderschuren (2017) go on to state that Germany, The United States of America, England, Wales, and Denmark use the CBA method. It should be noted that traditionally, Cape Town uses the CBA method, as well. The advantages highlighted is that it is well-structured, one dimensional, gives an economic result, in a transparent manner and a sensitivity analysis is possible. The disadvantages listed are that not all criteria can be converted to monetary value, involves many calculations to convert to monetary value, monetary values in different countries vary, discounts costs and benefits to future generations. van Wee & Geurs (2011) go as far as to state that the CBA is not suitable for evaluating social exclusion policies.

Analysis that only considers direct impacts and uses a short-term perspective tends to undervalue transit, especially rail (Litman, 2014). It was also found that conventional cost-benefit appraisal consistently yields higher benefit cost ratios for road projects than for most public transport investments (Marsay, 2017). According to Marsay, Eddington showed that the economic benefits could be up to 50% on top of direct vehicle operating cost (VOC) and value of time (VOT) benefits usually captured in transport CBA studies. The reason for this could be the importance placed on travel times, which may underestimate other criteria, such as environmental impact (Browne & Ryan, 2011). Lastly, it could be argued that many cost estimates have significant variation and uncertainty as some transportation studies lack details of assumptions and therefore, estimates may reflect lower costs (Browne & Ryan, 2011).

Alternatively, MCDA techniques involve a set of alternatives, criteria to be judged by, assigned weights, where possible and a method for ranking the alternatives based on how well they are judged by the criteria (Browne & Ryan, 2011). Munda (1995) as cited in Browne & Ryan (2011) states that MCDA are useful in developing potential social compromise solution and resolving conflicting interests by making a complex situation more transparent. MCDA promotes public participation and facilitates stakeholder involvement through structured but flexible decision-making in developing scenarios and undertaking assessment.

van Wee (2015) also points out that an MCDA is flexible and can relatively easily incorporate all accessibility measures and even multiple accessibility measure and in some cases, can explicitly show implications over different actors or actor categories. Browne & Ryan (2011) state that MCDA allows stakeholders to evaluate projects holistically, rather than taking a reductive approach by only evaluating costs. MCDA allows criteria to be included which is difficult to monetise.

However, it should be noted that the MCDA methods are not perfect. The weakness most often mentioned is the determination of criteria used, as well as weightings for criteria, which may lead to subjective and non-transparent biasing (Munda, 1995 as cited in Browne & Ryan, 2011).

Other flaws in the method include either distrust or excessive faith in the results, due to the ‘black-box’ nature of some of the methods (Munda, 1995 as cited in Browne & Ryan, 2011). Bruun & Vanderschuren (2017) go on to mention that South Africa, as well as Future World Bank Funded Projects evaluate projects using the MCDA method. The advantage of this method is that qualitative and quantitative dimensions can be included, the weighting of criteria creates transparency, handles vast amount of information and a sensitivity analysis is possible. The disadvantages include no direct sensitivity analysis and different methods may yield different results.

While it can be seen that the use of the MCDA method is not widespread for public transport evaluations, it was found that the number of transport projects evaluated using the MCDA method is exponentially growing, as shown in Figure 8.

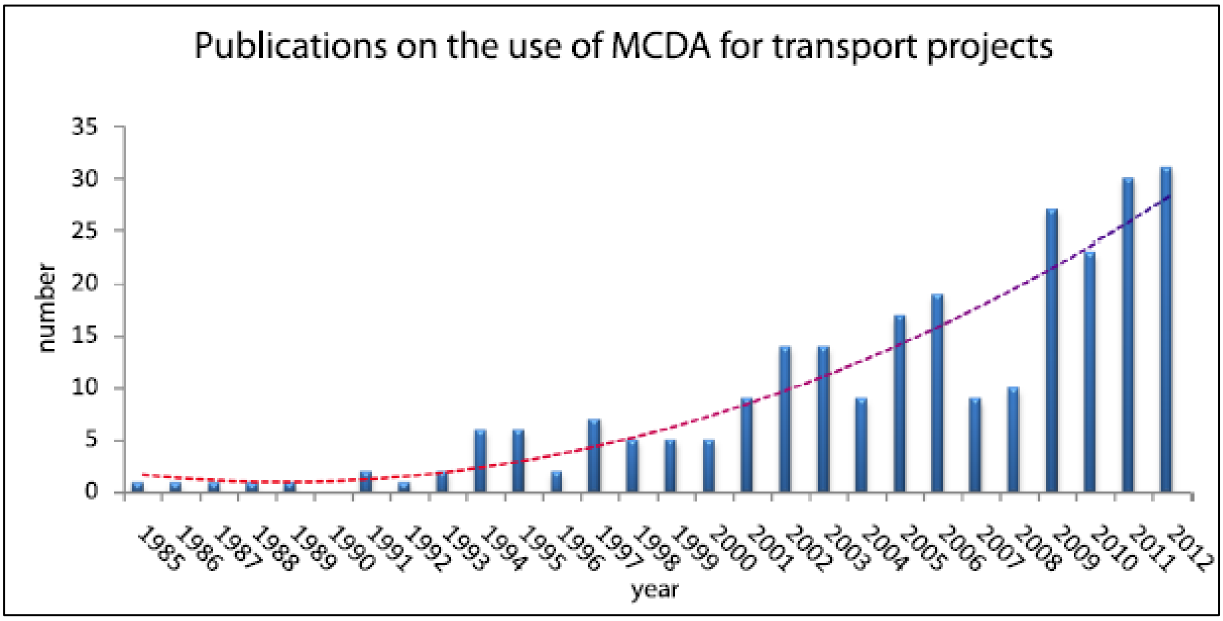

Figure 8: Evolution of the numbers of transport projects publications (period: 1985-2012)
Source: Macharis & Bernardini, 2015.

In order to include the previously excluded qualitative criteria as well as include the importance of financial implications, Bruun & Vanderschuren (2017); Browne & Ryan (2011), Beria, Maltese, & Mariotti (2012) and Beria, Bertolin, & Grimaldi (2018) recommend using an MCDA method that includes a CBA.

3.1.5 Time Periods to Evaluate

According to Chia-Lin Chen (2014), one of the key questions that should be asked when evaluating the effects of public transport on economic development is: When do wider impacts take place? It should be noted that some impacts occur in the short term, and other's take long-term, therefore, a life-cycle evaluation of public transport is necessary. The impacts can be evaluated in the following stages, as discussed in Chia-Lin Chen (2014).

The first stage is identified as the stage before the transport service is active, these include land use/re-development, property value and townscape image. These impacts are not caused by usage, they are impacted just by the planned infrastructure. The second stage is identified as the stage once the transport system is activated. There are new origins and destinations. Four kinds of impacts have been identified, these include, growth of consumer services, business operation and location, agglomeration effects and labour market and employment. These effects are seen as medium- to long-term effects.

The third stage is identified as the long-term stage, wider impacts that affect the urban spatial infrastructure is seen, as well as rebalancing of transport habits. However, there are arguments based on "How long is long term?" as collecting and comparing data over a long period is challenging. Aside from the impacts expected over the life cycle of public transport implementation, the cost over the life cycle also needs to be considered. In most cases, the ongoing costs of running the system (operations and maintenance) represent a much larger proportion of the total life-cycle costs of an improved system than the capital costs (South

Africa Department of Transport; South Africa National Treasury, 2018). The IPTN Plan Development Technical Guidance (2018) goes on to explain that the IPTN Plan is a long term (20+ years) strategy. It should be noted that for the sake of this research, only annual costs have been included.

3.1.6 Stakeholder Involvement

A stakeholder is, by definition, any individual or group of individuals that can influence or are influenced by the achievement of the organisation's objectives (Freeman, 1984, as cited in Macharis, De Witte, & Ampe, 2008). A number of stakeholders are involved in public transport project evaluations and each stakeholder has different perspectives, leading to different impacts (criteria) being a priority, (Mackie, 2010). This is shown in Table 5.

Table 3: Impacts by stakeholder of a transport project

Stakeholder Group	Impacts (changes in)
Transport users	Time Reliability Fares/costs Journey quality Perceived accident costs Option value
Transport operators/ Infrastructure providers	Revenues Operating costs Capital costs
Non-users	External accident costs Environmental impact
Rest of economy outside transport	Agglomeration Competitiveness Labour markets
Government	Subsidies Taxes Charges Grants

(Source: Mackie, 2010)

It can, therefore, be seen that some impacts are positive for some groups, and negative for the other (fares/costs for transport users versus operating costs for transport operators) (Mackie, 2010). Multi-Actor Multi-Criteria Analysis (MAMCA) allows evaluating different alternatives on the objectives of the different stakeholders that are involved. It explicitly includes the points of view of different stakeholders (Macharis *et al.*, 2012).

In MAMCA, a problem occurs when creating an extra layer of stakeholders in the analysis, it is felt necessary to attribute weights to the stakeholders. In all the MAMCA application so far, a pragmatic approach is followed, and all stakeholders are given an equal weight, in order to express each point of view on an equal basis (Macharis *et al.*, 2012).

It should also be noted that in the case of evaluating transport projects, when the government is one of the stakeholders, it is assumed that this stakeholder represents society's point of view and should therefore be the one to follow. Analysis of the points of view of the other stakeholders, like users, local population, manufacturers, and so on, will then show if a certain measure will possibly be adopted or rejected by these groups (Macharis *et al*., 2012).

For the sake of this work, a MAMCA is adopted and as previously mentioned three views will be analysed (specialist, academic (unbiased) and transport users).

3.2 Criteria Included in the Investigation

There are many ways that public transport projects are evaluated and part of the reason that a structured methodology is not used, is due to the complex nature of public transport.

The potential impacts are directly related to the range (e.g. economic, financial, environmental, social; direct/indirect) and affected groups (users, non-users, as well as government and private operators) (Ferreira & Lake, 2002).

A list of the indicators/impacts is shown in the table below.

Table 4: List of Indicators/Impacts (Source: Ustaoglu & Williams, 2019)

Indicators/Impacts
1. Direct impacts of transportation infrastructure provision: • Transportation facility land values • Infrastructure development and construction costs • Traffic services • Adjacent property values
2. Socio-economic impacts (*a. Land development impact)* • Green space preservation • Public service costs • Urban sprawl • Regeneration
b. Transportation-related impacts: • Safety • Vehicle ownership and operation costs • Transit fares • Travel time • Comfort and convenience • Traffic congestion effects • Transport diversity • Barrier effects

c. Socio-economic development impacts: • Affordability (housing) • Affordability (transport) • Social inclusion • Socio-economic growth • Wider economic impacts • Land use/transport accessibility • Area property values
d. Impacts on government fiscal balances • Changes in tax revenues • Marginal costs of public funds
3. Transport network effects: • Reliability • Quality of transport service • System operating and maintenance costs
4. Energy and environmental impacts: • Climate change emissions • Air/noise pollution exposure • Resource consumption costs • Water pollution • Waste disposal • Ecological impacts • Landscape and heritage

The various indicators / impacts listed above are used as part of the objectives when evaluating a public transport project.

The indicators mentioned above are discussed further in the sections below.

3.2.1 Direct impacts of transportation infrastructure provision:

Transportation facility land value refers to the cost of land used for transportation infrastructure construction and other public facilities dedicated for transport vehicle use (Ustaoglu & Williams, 2020). In evaluation, this will be measured in the cost of the land needed, which in different countries, would have different costs and methods associated with it. Due to South Africa's history, land ownership and acquisition is complicated (Hoffmann & Dilizo, 2018).

Infrastructure development and construction costs refers to the cost of designing and constructing transportation facilities including land and transport infrastructure construction (Ustaoglu & Williams, 2020).

Traffic services refers to the costs of police, emergency response, law enforcement, planning, street lighting, parking enforcement and driver training (Ustaoglu & Williams, 2020).

It should be noted that in countries where the minimum wage is considered high, employment costs account for up to 60% of the total service costs of public transport, whereas in countries where wages are low and unemployment is high, wages account for only 20%. Therefore, it can be seen that there is not much benefit to larger vehicles with fewer drivers, as they can lead to competition from small vehicles, such as the minibus taxis in South Africa (Gwilliam, 2009).

Adjacent property values refer to the change in real property values resulting from the provision and operation of the new transportation infrastructure (Ustaoglu & Williams, 2020).

According to Chen (2014), it was found that property values increase in close proximity to railway stations. Which is in agreement with the findings from Lombard *et al*., (2017) when investigating the value creation caused by the Gautrain. A general increase in residential property values in close relation to the Gautrain rail stations was found. Sectional title properties performed better than freehold properties after the construction of the Gautrain. However, at certain stations, a decrease in property prices was registered, which may be due to the noise caused during the construction phase (Lombard *et al*., 2017).

3.2.2 Socio-economic impacts (a. Land development impact):

Green space preservation: Refers to effects of transportation activities and facilities on the green space, e.g., parks, gardens, farms, woodlands, etc. (Ustaoglu & Williams, 2020).

Public service costs: These point to how costs of public service provision tend to increase with dispersion of urban activities (Ustaoglu & Williams, 2020).

Urban sprawl: Land development impacts vary by mode since private car-based transport requires more space than other modes for travel. Beyond the space needed for parking, car-based transport tends to encourage more dispersed patterns of land use. By contrast, alternative modes such as bus transit and rail systems are more likely to contribute to more compact and mixed-use land developments (Ustaoglu & Williams, 2020).

Regeneration: The provision of a new transport system associated with corresponding land use plans and policies can be influential in promoting urban renewal particularly in unfavourable urban areas (Ustaoglu & Williams, 2020).

In public transport project evaluation, double-counting of benefits needs to be avoided and, therefore, 'Adjacent property values' as discussed in 3.2.1 is linked to 'Regeneration'.

3.2.3 Socio-economic impacts (b. Transportation-related impact):

Safety: The ability of the transportation system to allow users to move freely without damage and harm (Ustaoglu & Williams, 2020).

Vehicle ownership and operation costs: Direct user expenses for the ownership and use of private vehicles (Ustaoglu & Williams, 2020).

Transit fares: Costs and revenues of public transport fares to the users and system providers (Ustaoglu & Williams, 2020).

Travel time: Time spent on transportation including waiting and actual travel time (Ustaoglu & Williams, 2020).

Comfort and convenience: This refers to the quality of the transport service including; the ride quality, crowding and the quality of information, cleanliness and ambience (Ustaoglu & Williams, 2020).

Traffic congestion effects: Refers to incremental delays, vehicle operating costs, transport-related pollution and stress resulting from interaction among vehicles in the traffic (Ustaoglu & Williams, 2020).

Transport diversity: The quantity and quality of travel options (particularly of non-drivers') are considered (Ustaoglu & Williams, 2020).

Barrier effects: Delays, discomfort, lack of access that roads and traffic cause to non-motorised travel (Ustaoglu & Williams, 2020).

The impacts listed above, are summarised by Litman (2014) below. In order to improve public transport, it is necessary to consider what needs to be improved to attract passengers. There are four general categories of transit improvements to consider:

1. Increased Service (more transit vehicle-miles) = reduction in travel time and possibly increased accessibility,
2. Improved Service (more comfortable, convenient, reliable, safety etc.),
3. Transit Use Incentives (lower fares, commuter financial incentives, marketing etc.), and
4. Transit Oriented Development (land use patterns designed to support transit, including more compact, walkable, mixed development around transit stations and corridors).

Since evaluating the effect of the public transport project on each criterion is challenging, a number of public transport evaluations were investigated to establish which criteria are often deemed to take priority. According to Zak (2010), the common characteristics from a user point of view, includes timeliness, operating frequency, safety, comfort, accessibility, riding time and travel costs. Along with the criteria listed above, service reliability has been shown to be a valued characteristic in travel mode choice (Gwilliam, 2009).

In order to rank the factors above, van Hagen (2018) created a Pyramid of Customer Needs shown in Figure 9.

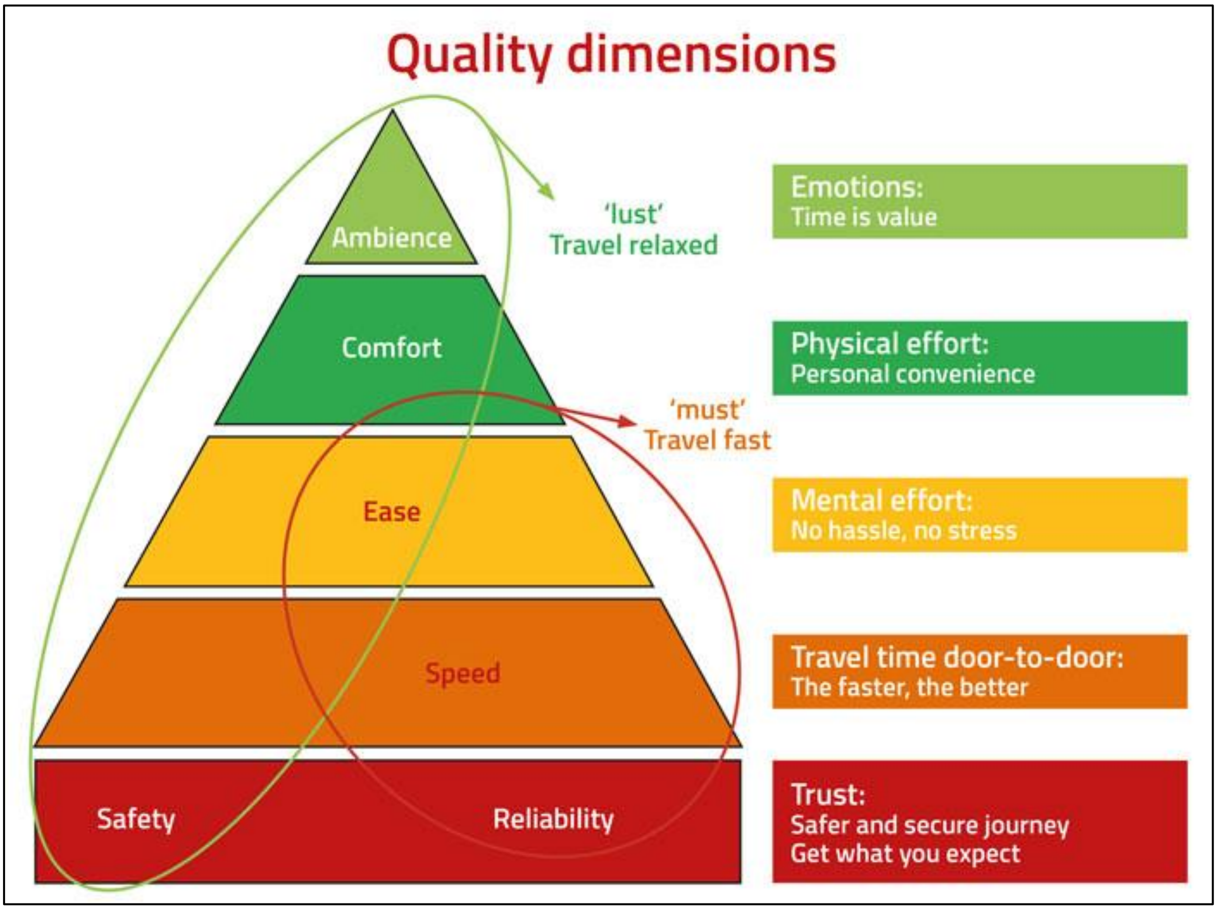

Figure 9: Pyramid of Customer Needs
Source: Adapted from Hagen, 2018

3.2.4 Socio-economic impacts (c. Socio-economic development impact):

Affordability (housing): The potential expansion of accommodation choices for all individuals to increase mobility and lower the combined cost of housing and transportation (Ustaoglu & Williams, 2020).

Affordability (transport): People's ability to access basic goods and activities (housing, medical care, food, education, work, and social facilities) by means of transportation (Ustaoglu & Williams, 2020).

Social inclusion: Transport-related factors influencing individual's ability to access education, employment and public services, social and recreational activities (Ustaoglu & Williams, 2020).

Socio-economic growth: The development and growth impacts of transportation infrastructure on the economy and society (Ustaoglu & Williams, 2020).

Wider economic impacts: Introduction of a local transport investment is influential in changing the effective density of employment and jobs that are accessible to the local economy. This will have further impacts on productivity and efficiency, i.e., agglomeration externalities, competition effects, output effects (of imperfect competition) and labour market effects (Ustaoglu & Williams, 2020). This was seen during a study of labour markets in London and Paris, where the effect of public transport to the economy was indirectly seen. It was found that labour productivity, throughout various employment types, was higher in Paris than it was in London. Upon further investigation, it was found that the innermost part of London had a productivity level that was even higher (Marsay, 2017).

London, like most transport corridors, has radial routes terminating at the perimeter of central London, which makes accessing the innermost area of London convenient. It can also be seen that the number of trip opportunities and routes became denser within the innermost circle of London (Marsay, 2017). London's transport system does not cater to trips anywhere outside of the inner hub of London. Therefore, employees do not have access to the greater London area and, therefore, workers had a smaller number of jobs available to them within short travel times (Marsay, 2017).

Paris, on the other hand, attempted to provide access to the entire area of Paris by providing radial and orbital transport infrastructure, therefore, a trip length of approximately 1 hour would provide access from any Point A within Paris to any Point B. Workers, therefore, had access to a larger area and a wider variety of jobs. Although the trip routes and options become denser nearing the centre of the city, a larger number of routes exist outside of the city (Marsay, 2017).

Although it seemed as though Paris was "over-investing" in their transport infrastructure, the benefits received were found in higher labour productivity, which in turn contributed to the economy and social wellbeing of inhabitants, those benefits, however, are challenging to quantify (Marsay, 2017). This is indirectly linked to the criteria 'Land use/transport accessibility'.

Land use/transport accessibility: The ability of the transportation system to connect people to goods, services, and activities, and to meet needs of different populations (Ustaoglu & Williams, 2020).

Area property values: Transportation policies and planning decisions have influences on property values as well as the location and type of real property development (Ustaoglu & Williams, 2020).

Again, it should be mentioned that in public transport project evaluation, double-counting of benefits needs to be avoided and therefore, linked to 'Area Property values', is 'Adjacent property values' and 'Regeneration' as discussed in 3.2.1 and 3.2.2, respectively.

3.2.5 Socio-economic impacts (d. Impacts on government fiscal balances)

Changes in tax revenues: These represent changes in transport-based tax revenues following a demand shift among different transport modes (Ustaoglu & Williams, 2020).

Marginal costs of public funds: Refers to the impacts of transport projects on public funds through the need to finance capital expenditures and the impact of the project on taxation receipts (Ustaoglu & Williams, 2020).

3.2.6 Transport network effects:

Reliability: Variation and consistency in travel times and the reliability related to external factors (Ustaoglu & Williams, 2020).

Quality of transport service: Relates to ride quality, crowding, ambience and quality of information (Ustaoglu & Williams, 2020).

System operating and maintenance costs: Refer to expenditures to maintain the transport facilities including maintenance and operations (Ustaoglu & Williams, 2020).

'Reliability' and 'Quality of Transport Services' is linked to the criteria listed in 3.2.3 and careful consideration should be made not to double-count the effects of the public transport alternative.

3.2.7 Energy and environmental impacts:

Climate change emissions: Refers to the greenhouse gases (i.e., CO2, NOx, CH4) emitted from transportation vehicles and related facilities that increase atmospheric solar heat again (Ustaoglu & Williams, 2020).

Air/noise pollution exposure: The noise and air pollution associated with transportation system construction/operation (Ustaoglu & Williams, 2020).

Resource consumption costs: These refer to various direct and indirect costs of energy produced, distributed, and used in vehicle and transport facility construction and operation (Ustaoglu & Williams, 2020).

Water pollution: Pollution (surface and ground water) associated with transportation facilities and vehicle use (Ustaoglu & Williams, 2020).

Waste disposal: External costs resulting from vehicle waste disposal activities (Ustaoglu & Williams, 2020).

Ecological impacts: Transport infrastructure and operation impacts on flora, fauna, and their habitat such as wetland, (Ustaoglu & Williams, 2020).

Landscape and heritage: Transport networks and related facilities, vehicle traffic and low-density development can be a threat to cultural heritage and often degrade landscape beauty (Ustaoglu & Williams, 2020).

3.3 External Factors Affecting Public Transport Evaluation

There are other external factors that affect the success or failure of the improvement or introduction of public transport. According to Chen (2014), these factors include:

1. The existing condition of the area: The existing state of an area will affect the outcome of the public transport investment. A thriving area may only be held back by congestion; therefore, scholars argue that investment acts merely as a catalyst and channel development that would have occurred anyway elsewhere in the region. Therefore, the potential for development should already have existed.

   However, this implies that lagging areas should not have public transport introduced. Vanderschuren *et al*., (2021) argues that identifying and minimising transit deserts could be a powerful mechanism for bridging the economic divide and enabling broader and more equitable urban access in Cape Town, South Africa. The provision of transit service will influence the demand. This implies that the existing economic state should be considered, as well as future predictions and trends. A recession would impact the wider effects, such as job creation and the labour market, should the recession end or improve, the positive impacts would also improve.

2. Constitutional Capacity and Political Leadership: The structure of the Government plays a key role. Various government levels (national, regional, or sub-regional) have different priorities and budgets. Issues will be easier addressed if there is a consolidated decentralised process for regional, metro, and intercommunal governance than for a centralised system.

3. Integrated Land-Use and Transport Planning Policies: Active local government planning policies are important factors which affect development. These policies include: floor area ratios, zoning, marketing of air rights, sale of excess land and urban renewal, park and ride programmes and more. There must be co-ordination between transport investment and land-use in order to encourage or unlock benefits of the investment.

4. Financial and Funding policies: Transport systems are often financed privately or partially. The financial contribution can also be indirectly in the form of private developments along a transport corridor, which creates the indirect benefits previously mentioned, such as job creation etc. However, a private investor will only invest should they be sure that the public transport system will uplift the area, the surrounding property values, or make a profit – if this is unlikely, the government will need to implement a system to subsidise the transport system or implement policies, which will encourage the private sector to contribute and invest.

5. Community Involvement: This is vital and should be done early on in planning. Key community members include local businesses, residents, transport users, institutional

representatives etc. In South Africa, community objections can cause delays, or entirely stop a project.

It should be noted that along with the factors discussed above, the success of public transport is influenced by the ridership, since a number of impacts are estimated on the forecast of ridership (Ferreira & Lake, 2002). There is little benefit to society from public transport simply being introduced and operated, most of the benefits depend on how much the service is used, thereby reducing congestion, wear and tear on roads, parking lot expansions etc. (Litman, 2014). Further the criteria and impacts mentioned above are both direct and indirect. Direct benefits or effects results from an increase in mobility provided by the transit and a reduction of automobile use, whereas indirect effects or benefits result when a major improvement in transit use provides a catalyst for more accessible land use patterns and a more diverse system that leads to additional reductions in automobile use (Litman, 2014).

According to Marsay (2017), it should also be noted that gains are higher when new transport infrastructure in being introduced versus upgrades to already existing infrastructure. The negative image of Metrorail would be difficult to overturn, as PRASA is investing in maintenance of the existing infrastructure and, therefore, passengers are not experiencing an improvement in service.

4 CASE STUDY: CAPE TOWN PUBLIC TRANSPORTATION MODES

This research investigated the existing state of public transport in Cape Town and possibilities of improving the method used in evaluating public transport projects. Along with the literature review, further investigations and assumptions were made in order to identify the modes and criteria being evaluated, as well as the methods used for the evaluation.

4.1 Criteria Analysed

In order to distinguish which criteria would be used in this study, official statements and governmental documents were evaluated in order to establish trends in criteria mentioned regarding public transport in South Africa. A number of sources were considered, including South African President Cyril Ramaphosa's speech at the Transport Month Launch (2019), the Budget Vote Speech (2019), State of the Nation Address (2015-2020), Guidelines for the implementation of the Integrated City Development Grant (2013-2014), Performance and Expenditure Review, and the Integrated Public Transport Network (IPTN) Plan Development (2018).

While all the sources were considered, the IPTN Development Plan (2018) was found to be the most informative as the document clearly stipulates the criteria considered during public transport project evaluation. The recommended criteria are, in no particular order:

- Public transport system performance (e.g., travel times, reliability, transfer rates),
- Non-motorised system performance (e.g., coverage, condition),
- Traffic safety (e.g., accident, fatality rates),
- Social goals (e.g., improving access for low-income households to jobs, healthcare, and education, making public transport more affordable for the poor, reducing public transport travel times and other aspects of travel difficulty),
- Developmental goals (e.g., building of business capabilities and opportunities for previously disadvantaged groups in the provision of services),
- Environmental goals (e.g., reducing local and greenhouse gas emissions),
- Land use (e.g., the degree to which an alternative might induce non-motorized and transit-oriented land development; the possibilities for increasing public open space),
- Financial efficiency (e.g., improving the financial performance of public transport),
- Cost-effectiveness/ value for money, (e.g., the life cycle (all capital, operating and maintenance costs) of achieving transportation objectives such as travel time savings, accident and emission reductions),
- Affordability for users; and / or
- Financial sustainability for the responsible local and provincial governments.

Using the recommended criteria and sub-criteria above as a guideline, a word count was performed on the statements and press releases previously mentioned. The ranking of the top ten mentioned criteria/impacts are:

1. Cost-effectiveness,
2. Land-Use and Integration,
3. Affordability for Users,
4. Social Goals (Access),
5. Public transport system performance (Speed),
6. Public transport system performance (Convenience & Reliability),
7. Environmental Goals,
8. Public transport system performance (Reliability),
9. Traffic Safety, and
10. Developmental Goals.

To ensure that the MCDA does not double-count, the criteria as used is outlined below.

4.1.1 Cost-effectiveness

Public transport projects will only receive funding if the project is deemed to be 'fiscally and financially sustainable', i.e. affordable over the long term (South Africa Department of Transport; South Africa National Treasury, 2018). This means that there should be sufficient revenue (including fares, grants, local taxes, loans) to cover all costs, including recurring ones (South Africa Department of Transport; South Africa National Treasury, 2018). Transit system costs are fairly easy to determine, however, identifying all the incremental benefits poses to be onerous. In addition to this, some of the benefits are difficult to monetise. These benefits/impacts should be quantified as much as possible (Litman, 2014). Since a MCDA is being used in this investigation, a number of impacts that are usually monetised, such as travel time, etc. will not be monetised as travel time will be evaluated independently. Therefore, the "Cost-effectiveness" criteria include estimated annual costs (South Africa Department of Transport; South Africa National Treasury, 2018), which will be measured in Rands. It should be noted that the consequence of excluding travel time savings from cost-effectiveness would limit comparison with other studies where cost-effectiveness was included.

4.1.2 Land-Use and Integration

Land-Use and Integration refer to the degree to which an alternative might induce non-motorized and transit-oriented land development; the possibilities for increasing public open space, e.g. making areas more pedestrian friendly, which in turn will make public transport more efficient and effective (South Africa Department of Transport & South Africa National Treasury, 2018). Progressive spatial transformation aimed at reducing trip distances and encouraging more bi-directional passenger movements will in the medium to long term improve the fiscal and financial sustainability of the system (South Africa Department of Transport & South Africa National Treasury, 2018).

According to Litman (2009), Land-Use Impacts include the following, as shown in Table 7 below.

Table 5: Land-Use Impacts (Source: Litman, 2009)

Economic	Social	Environmental
• Value of land devoted to transportation facilities. • Land use accessibility. • Transportation costs. • Property values. • Crash damages. • Costs to provide public services. • Economic development and productivity. • Stormwater management costs.	• Relative accessibility for different groups of people – impacts on equity and opportunity. • Community cohesion. • Housing affordability. • Cultural resources (e.g., heritage buildings). • Traffic accidents. • Public health (physical fitness). • Aesthetic impacts.	• Greenspace and wildlife habitat. • Hydrologic impacts. • Heat island effects. • Energy consumption. • Pollution emissions.

In addition to Table 7 land-use patterns can be evaluated based on the following attributes:

- Density - the number of people, jobs, or housing units in an area,
- Clustering - whether related destinations are located close together (e.g., commercial centres, residential clusters, urban villages, etc.),
- Mix - whether different land use types (commercial, residential, etc.) are located together,
- Connectivity – the number of connections within the street and path systems,
- Impervious surface – land covered by buildings and pavement, also called the footprint,
- Greenspace – the portion of land used for lawns, gardens, parks, farms, woodlands, etc. The Green Area Factor or Green Area Ratio (GAR) refers to the percentage of land that is greenspace,
- Accessibility – the ability to reach desired activities and destinations, and
- Non-motorised accessibility – the quality of walking and cycling conditions.

For the sake of this case study and to avoid double-counting, the value of land devoted to transportation facilities (measured in square metres / rands) was used. While it is noted that certain modes provide higher levels of non-motorised accessibility, it is not considered part of the scope of this research.

4.1.3 Affordability for Users

The affordability for users was measured by the estimated cost of travel, in Rands. Indirect financial benefits to users were not considered in this criterion, to avoid double counting and vague results. The data obtained was compared to the goal stipulated in the National Transport White Paper Policy, "[t]o ensure that public transport is affordable, with commuters spending less than about 10 percent of disposable income on transport" (Department of Transport , 1996).

4.1.4 Social Goals (Access)

The "Access" criteria refer to the accessibility of the public transport mode introduced / improved. Accessibility analysis looks at the performance of the proposed public transport project providing access to different kinds of life activities, such as employment, school, healthcare, shopping etc. within time and cost constraints (South Africa Department of Transport; South Africa National Treasury, 2018). Accessibility also considers social inclusion and the extent of the availability of international standards of accessibility.

It should be noted that ***Speed, Convenience*** and ***Reliability***, as discussed below, directly affect Accessibility, in the broader sense. Therefore, in this study, Geographic Accessibility was focused on, i.e., distances between activities and public transport. This was evaluated using ArcGIS, the placement of stops and the percentage of Cape Town that is covered by the existing placement of stations / stops.

4.1.5 Speed

The "Speed" criteria refer to the speed of the vehicle, which is tied to the travel time. Therefore, this criterion will be measured as User Travel Time (in-vehicle). Assumptions on how User Travel Time was calculated will differ for each mode and is discussed in each scenario. The User Travel Time was measured in minutes, to avoid additional errors in converting to cost.

4.1.6 Convenience & Reliability

It should be noted that the "Convenience & Reliability" criteria were combined and as mentioned, ties in with "Accessibility" and "Speed" as convenience of public transport is often relative to the ease of access as well as the travel time. "Convenience" focused on crowd density, as well as other available facilities at stations, namely, toilets, retail, seating, air-conditioning, etc. The "Reliability" criterion referred to the punctuality of the public transport mode. This was evaluated based on the National Household Transport Survey (NHTS) 2013.

4.1.7 Environmental Impacts

The "Environmental Impacts" refer to the impacts the various modes of transportation will have on the environment. For the sake of this research, the study focused on an estimation of grams of CO_2 per passenger kilometre based on the secondary data available.

4.1.8 Safety

The "Safety" criterion is two-fold, referring to both the safety and security of the user, as well as of the public transport mode. This was evaluated based on the NHTS (2013).

4.1.9 Economic Development

The "Economic Development" criterion refers to the effect of public transport implementation on the economy. Economic growth is linked to a number of factors. Direct factors, such as an increase in employment directly linked to new public transport, and an increase in time and cost savings. There are other indirect and induced factors, such as an increase in accessibility and mobility, leading to the growth factors of employment reach and purchases in materials and services directly linked to the public transportation (Rodrigue & Notteboom, 2020). Based on the above, the criterion 'Economic Development' was not included in the MCDA as the effects of public transport on employment and access will be measured in 'Access', 'Speed' and 'Land-Use Integration'.

4.2 Criteria Selection

Based on the above, the criteria were grouped into objectives and sub-objectives.

1. Cost,
2. Land-Use,
3. Affordability for Users,
4. Accessibility,
5. Estimated Speed,
6. Convenience & Reliability,
7. Environmental Effects, and
8. Safety & Security.

4.3 Scenarios Analysed

4.3.1 Existing Rail

The current available rail services in Cape Town was evaluated. i.e. MetroRail's reach around Cape Town. MetroRail, governed by Passenger Rail South Africa (PRASA) is a public entity wholly owned by the government and reports to the Minister of Transport (PRASA, 2021).

This is shown graphically in Figure 10 each station is represented by a white circle. The data was received from the Directorate Provincial Spatial Information, Department of the Premier, Western Cape Government.

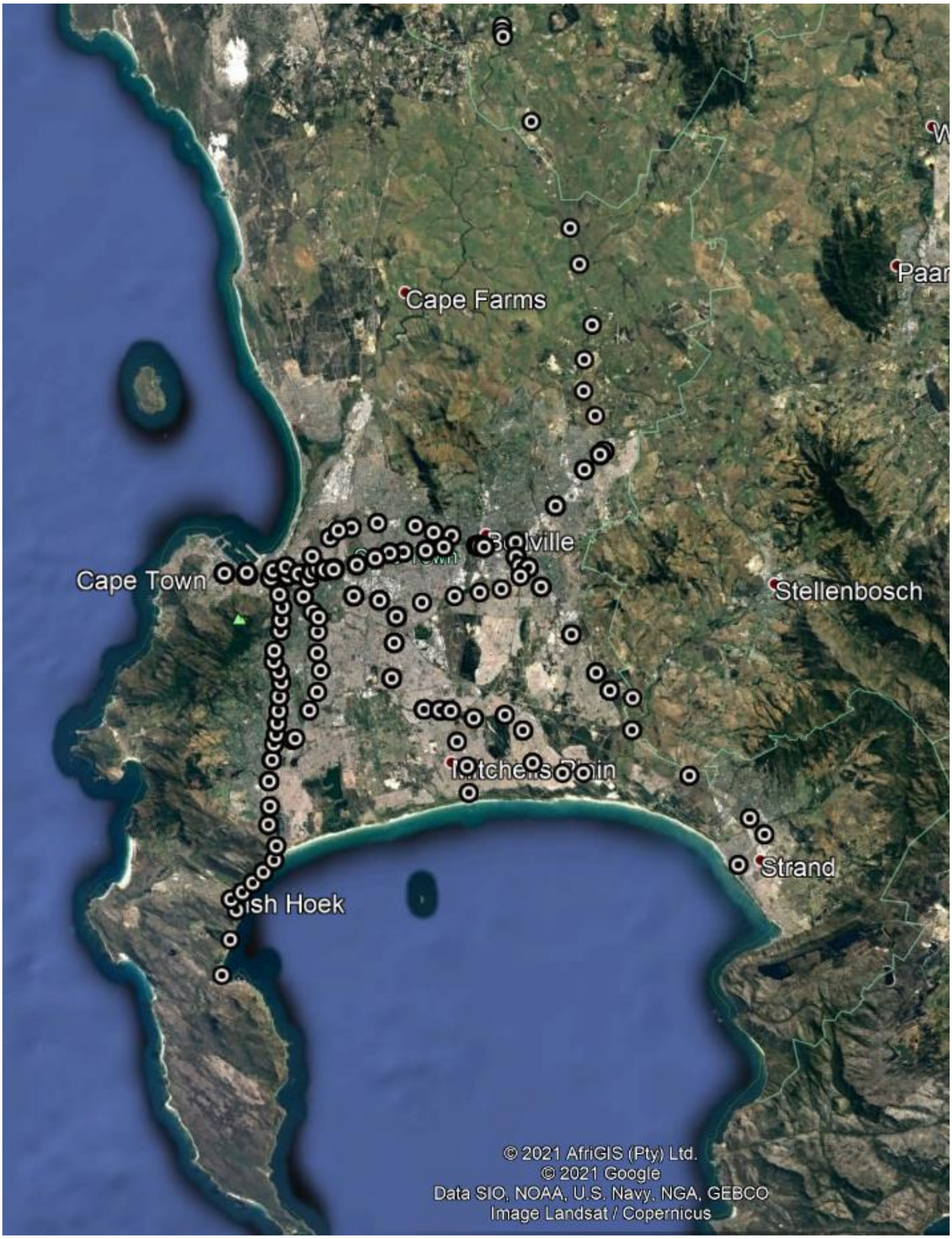

Figure 10: Locality plan showing the MetroRail stations in Cape Town being investigated (Source: Google Earth, 2021)

A diagram showing the Metrorail routes is included in Figure 11.

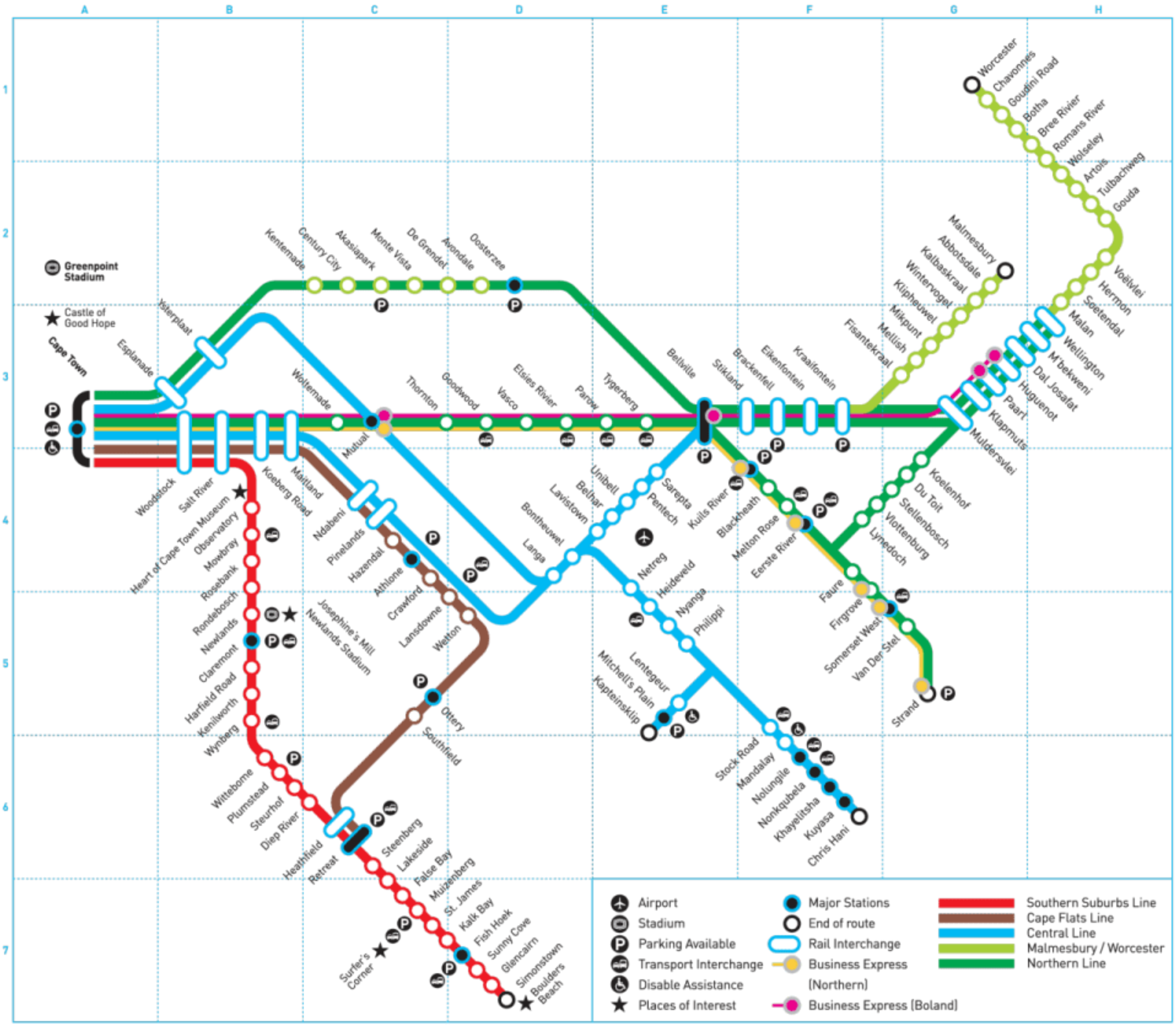

Figure 11: MetroRail Routes (Source: Transitmap.net)

As can be seen in Figure 11 the major routes available are:

1. Southern Suburbs Line from Simonstown, through Retreat, Claremont, ending in the City of Cape Town.
2. Cape Flats Line from Retreat, through Ottery and Athlone, ending in the City of Cape Town.
3. Central Line from Chris Hani (Khayalitsha), through Mitchell's Plain ending in the City of Cape Town with rail interchanges at Bellville and Mutual (Pinelands).
4. Malmesbury/Worcester Line from Malmesbury or Worcester ending in the City of Cape Town.
5. Northern Line from Strand or Wellington, through Kraaifontein and Bellville, ending in the City of Cape Town.

As can be seen, the service predominately runs between Bellville and the City of Cape Town. The existing corridor services urban residential, rural areas and industrial areas. The existing corridor runs mostly at-grade, physically separated from the vehicular traffic. The corridor has formal stations with a fixed timetable.

4.3.2 Existing Bus Service

The current available bus services in Cape Town is evaluated. i.e. Golden Arrow's reach around Cape Town. The Golden Arrow Bus Stops are shown in Figure 12 as indicated by a white square. The data shown below was obtained from the City of Cape Town Open Data Portal.

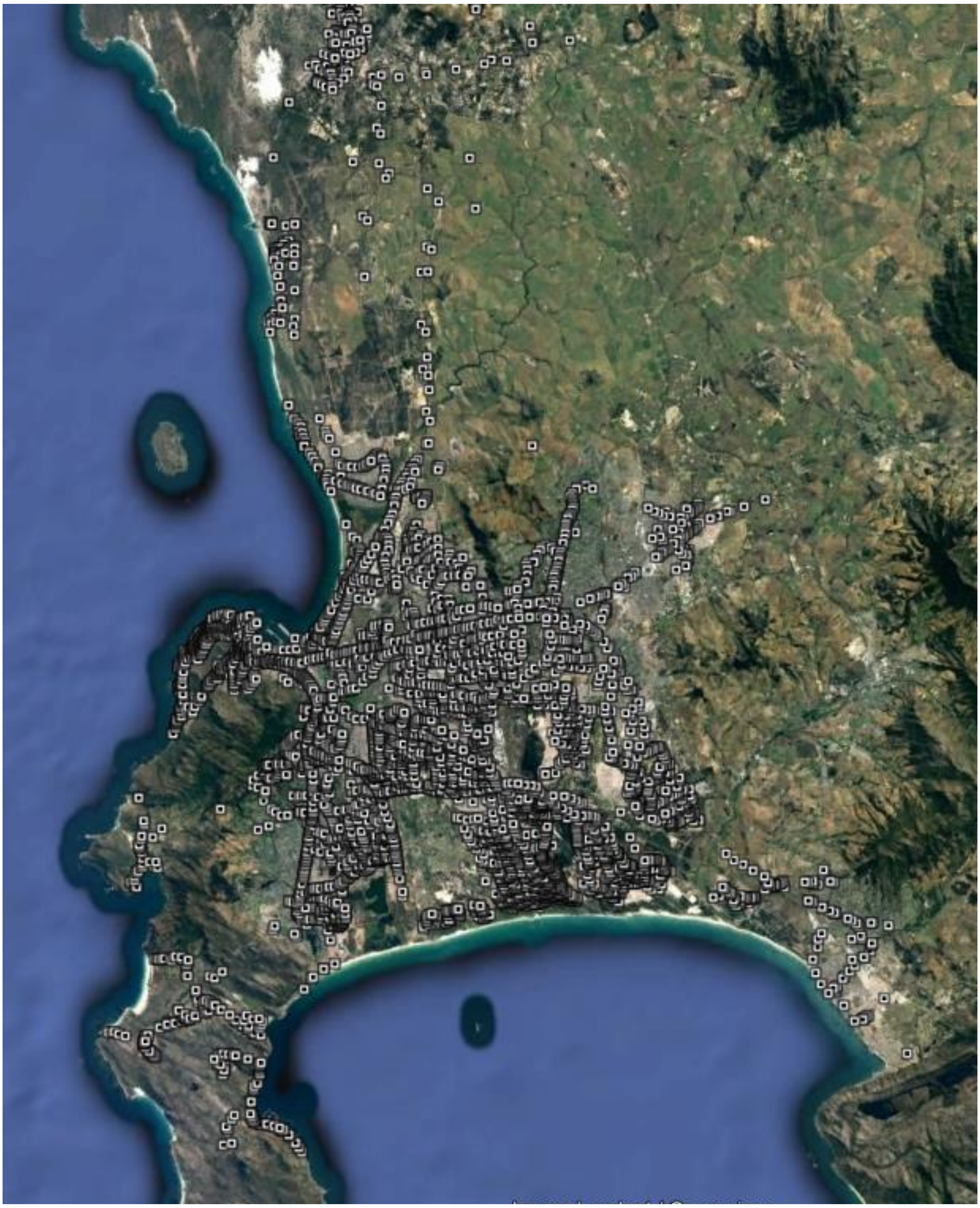

Figure 12: Locality plan showing the bus stops in Cape Town being investigated (Source: Google Earth, 2021).

Figure 12 shows that bus stops cover a large portion of Cape Town, this is discussed later when evaluating accessibility. The Golden Arrow Bus Service operates 1 066 busses during peak and has seven strategically placed depots as listed (Golden Arrow Bus Services, 2017).

The existing service runs along the public road and bus stops range from formal sheltered stops with embayments to stops where the bus would stop in-road. The service is scheduled.

The predominate routes covered by the bus service include:

1. Montana,
2. Philippi,
3. Philippi (Southgate)
4. Blackheath,
5. Woodstock,
6. Atlantis, and
7. Simonstown.

4.3.3 Existing BRT Service

The current BRT system in Cape Town is known as the MyCiTi Bus Service introduced in 2010 to assist during the 2010 FIFA World Cup. The existing MyCiTi Bus Stops are shown below indicated by a white star. The data was obtained from the City of Cape Town Open Data Portion.

The MyCiTi service has on certain routes, a dedicated lane to speed up transport, as well as formal stops and stations. The MyCiTi is scheduled. The service has 4 trunk routes with stops along the way:

1. Dunoon – TableView – Civic Centre – Waterfront,
2. Atlantis – Table View – Civic Centre,
3. Atlantis – Melkbosstrand – Table View – Century City, and
4. Dunoon – Omuramba – Century City.

In addition to this, there are 9 direct routes:

1. Khayalitsha East – Civic Centre,
2. Khayalitsha West – Civic Centre,
3. Mitchell's Plain East – Civic Centre,
4. Kapteinsklip – Mitchell's Plain Town Centre – Civic Centre,
5. Dunoon – Parklands – Table View – Civic Centre – Waterfront, and
6. Dunoon – Montague Gardens – Century City.

The MyCiTi service has additional feeder services which transport passengers to the direct and trunk route.

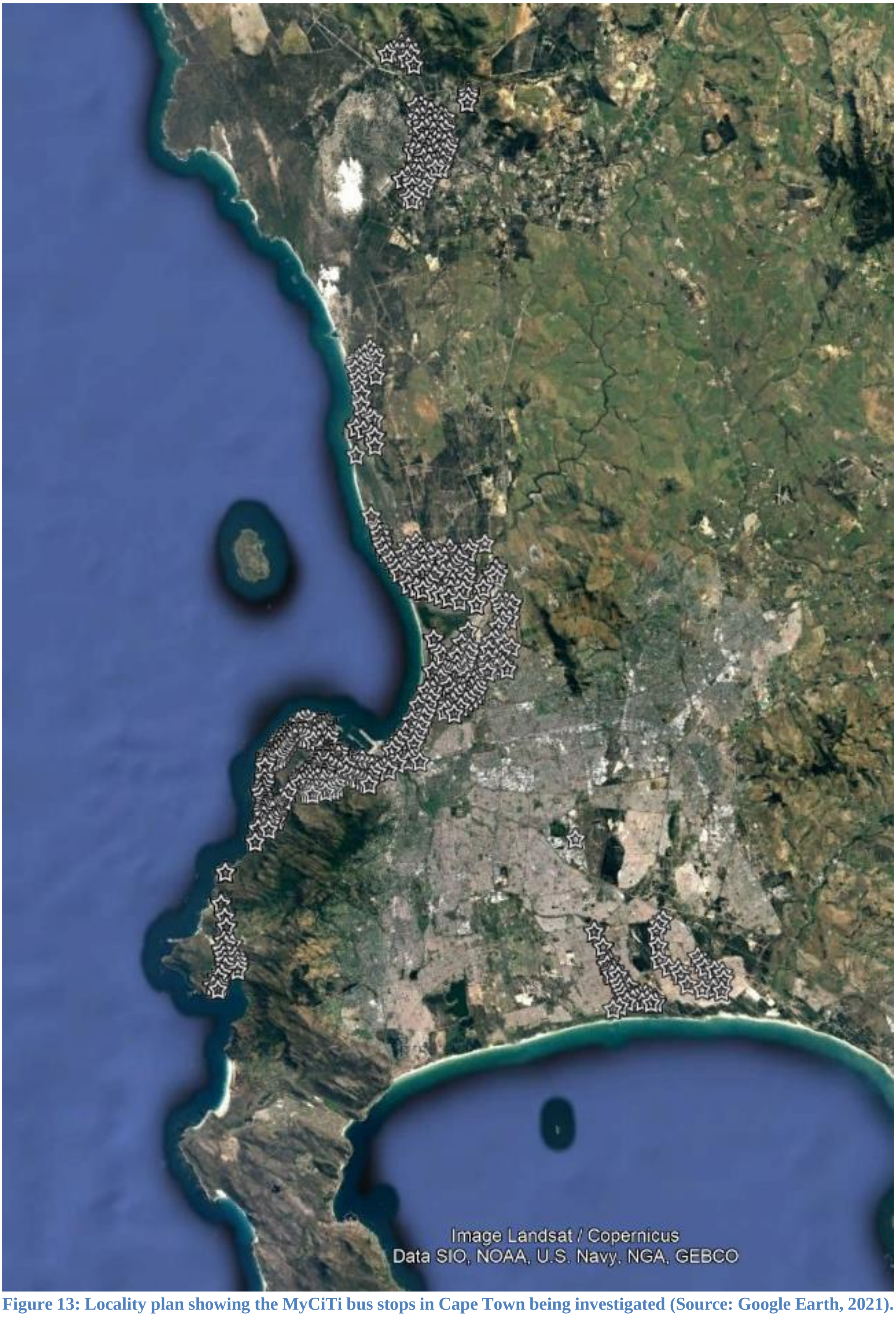

Figure 13: Locality plan showing the MyCiTi bus stops in Cape Town being investigated (Source: Google Earth, 2021).

4.3.4 Existing Minibus Taxi Service

The current minibus taxi service in Cape Town was evaluated. The service is unscheduled and minibus taxis are known to stop in locations without formal stops. The service operates using cash only. The Western Cape Government Taxi Industry Regulation 2020 stated that in the Western Cape 20 000 operating licences have been issued. However, it is estimated that in South Africa an additional 63 000 – 100 000 minibus taxis are operating illegally (Department of Transport, 2020).

Minibus Taxi Ranks are located all around Cape Town and routes can be classified as trunk, intermediate and feeder/distribution routes. These are shown in Figure 14.

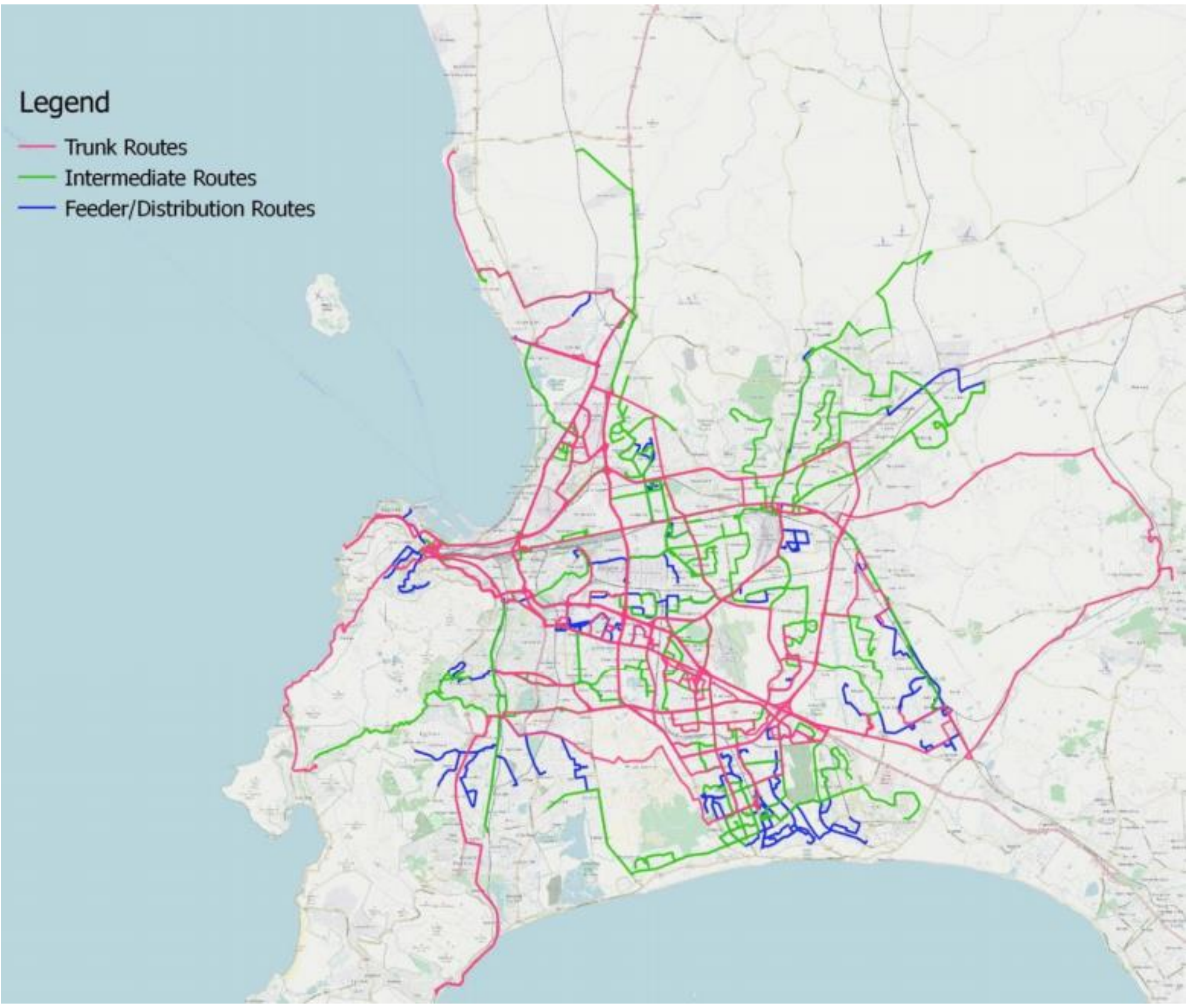

Figure 14: Trunk, intermediate and feeder/distribution routes in Cape Town for minibus taxis Source: (du Preez, 2018))

4.3.5 Proposed Integrated Public Transport System

The proposed integrated public transport system has not been designed and is, therefore evaluated theoretically. The integrated public transport system assumes the following:

- The existing rail service will continue operating.
- The existing BRT service will continue operating.
- The existing bus service will continue operating.

- The existing minibus taxi service will operate as feeders to the existing rail and BRT services.
- An integrated cashless system is used. One card for all modes of public transport.

In addition to this, the following is assumed:

- The BRT system would not be expanded, with the available funds used to upgrade the existing public transportation along the proposed routes.
- A new organisation is formed to govern public transport considering that at the moment the public transport systems are governed both privately/publicly by different organisations.

In order to create a graphical representation of the accessibility and layout with all services operating, Figure 15 below shows the MetroRail stations (yellow train icon) and MyCiTi stops (white star icon) along with the minibus taxi routes (red lines) and Golden Arrow bus stops (blue bus icon).

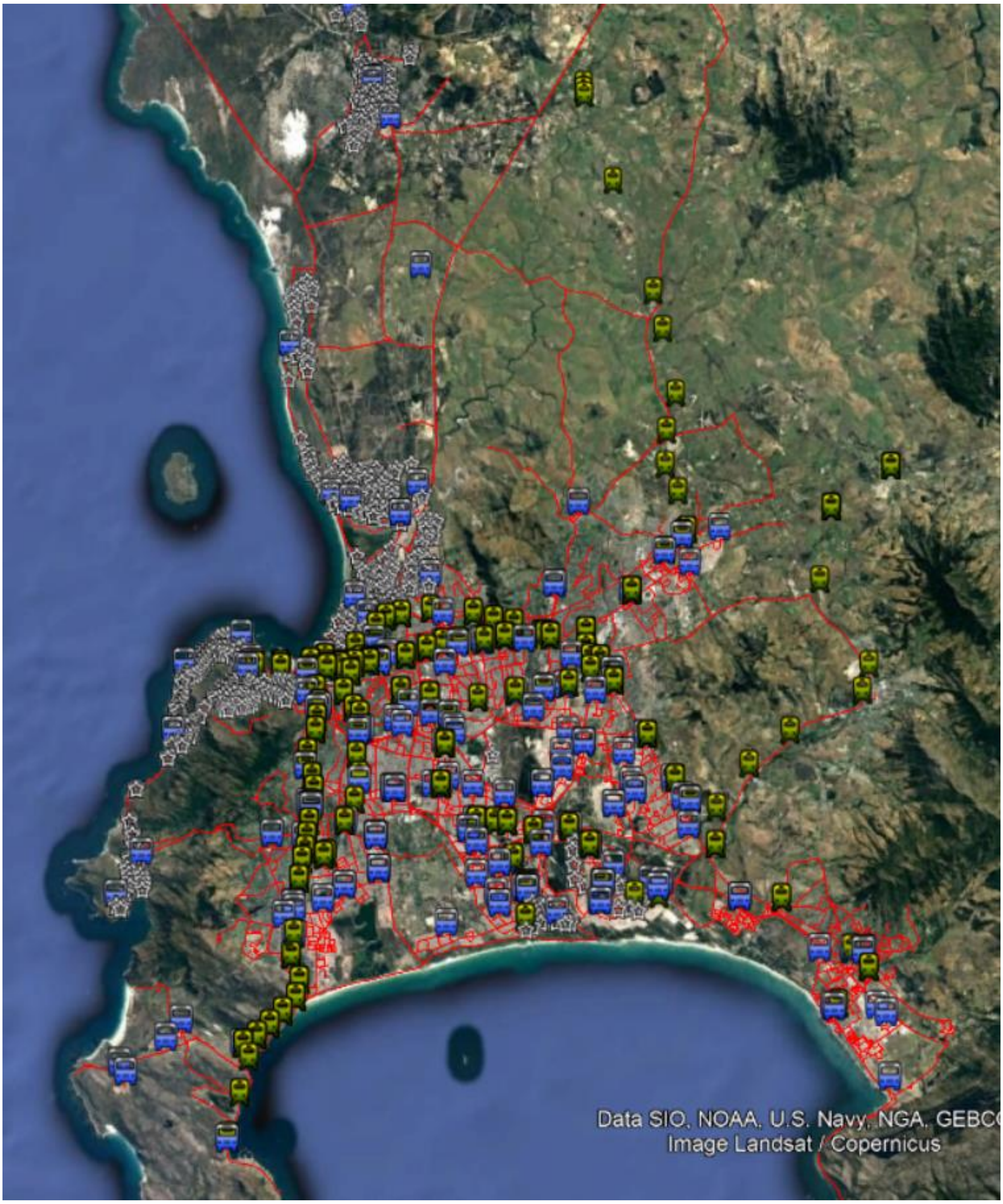

Figure 15: Locality Plan showing the MyCiTi, MetroRail, Golden Arrow and minibus taxi stops being analysed as part of an integrated transport system in Cape Town (Source: Google Earth, 2021).

As can be seen in Figure 15, the routes covered would be the same routes as covered by the existing services, independently. However, to increase efficiency, certain services would not run in parallel.

The trunk routes proposed include the existing trunk routes from MetroRail, which service the southern and northern suburbs, and are supported by existing Golden Arrow services to provide options for users, as well as additional supply. MyCiTi, which services the west coast will be the main mode and be supported by the existing rail to provide options for users as well as additional supply – both MetroRail and MyCiTi public transport modes currently service a central / Cape Flats route as well and, therefore, do not need support from Golden Arrow busses. Instead for the central / Cape Flats line the minibus taxis will operate as the supporting mode. The minibus taxis would operate as feeders into the main modes (MetroRail / MyCiTi), which will be necessary as the number of stops will be reduced to ensure less travel time.

The proposed routes are therefore as follows:

1. (MetroRail) Southern Suburbs Line from Simonstown, through Retreat, Claremont, ending in the City of Cape Town.
2. (MetroRail) Cape Flats Line from Retreat, through Ottery and Athlone, ending in the City of Cape Town.
3. (MetroRail) Central Line from Chris Hani (Khayalitsha), through Mitchell's Plain ending in the City of Cape Town with rail interchanges at Bellville and Mutual (Pinelands).
4. Parallel to point 3 listed above: (MyCiTi) Khayalitsha to Civic Centre and
5. (MyCiTi) Mitchell's Plain East – Civic Centre
6. (MetroRail) Malmesbury/Worcester Line from Malmesbury or Worcester ending in the City of Cape Town.
7. (MetroRail) Northern Line from Strand or Wellington, through Kraaifontein and Bellville, ending in the City of Cape Town.
8. (MyCiTi) Dunoon to TableView – Civic Centre – Waterfront.
9. (MyCiTi) Atlantis to Table View – Civic Centre.
10. (MyCiTi) Atlantis to Melkbosstrand – Table View – Century City.
11. (MyCiTi) Dunoon to Omuramba – Century City.
12. (MyCiTi) Dunoon to Parklands – Table View – Civic Centre – Waterfront.
13. (MyCiTi) Dunoon to Montague Gardens – Century City.

As this is entirely theoretical, broad assumptions were made in order to perform the comparative analysis.

4.4 Evaluation of The Different Modes

This section quantifies the selected criteria discussed in Section 4.1. for the modes of transport mentioned in Section 4.3. It should be noted that as secondary data was used, a number of assumptions were made in order to quantify the data.

4.4.1 Cost

The "cost" as previously discussed refers to average operating costs and maintenance of infrastructure per km travelled over a certain period of time. As mentioned, it is recommended that during further research, primary data is collected to reflect more accurate results, however for the sake of this investigation, averages were used as described below.

METRORAIL

According to the 2020 – 2022 PRASA Corporate Plan, the 2017/2018 operational expenditure for passenger rail, used for MetroRail, was found to be R833 446 322 over a distance of 38 262 447 kilometres travelled. Therefore, the cost calculated equates to approximately: **R21.78/km** (PRASA, 2017-2020)**.**

GOLDEN ARROW BUS SERVICE

According to HPL&R 2019 Corporate Report, the total operating expenses for Golden Arrow services in 2019 were approximately R1.382m, the cost of new busses purchased in 2019, equated to approximately R156m and the number of kilometres travelled equated to approximately 60m. Therefore, the cost calculated for the Golden Arrow services is approximately **R25.65/km** (HPL&R, 2019)**.**

MYCITI SERVICE

According to the MyCiTi Business Plan (2015) it is estimated that in 2014, the MyCiTi Bus Service spent approximately R1bn and travelled, approximately, 12.4 million kilometres and while these are not recent figures, it is unfortunately the only data available. The cost for 2014, therefore, equates to approximately: **R85.2/km.** It should be noted that simply escalating the costs associated with the MyCiTi service does not take into account the new phases of which the total construction costs are unknown (MyCiti, 2015).

For example, according to data received from SMEC South Africa, the construction of Phase 2A Trunk Infrastructure: Jan Smuts Drive from Turf Hall Road to Govan Mbeki Road (approximately 2.5 kilometres of IRT dual road plus two general traffic lanes per direction, cost approximately R31m. It should, therefore, be noted that in addition to IRT dedicated lanes, general roadworks are often required.

MINIBUS TAXI SERVICE

According to SANTACO, it is estimated that in South Africa, the minibus taxi industry consumes petrol to the combined value of R15bn, spends R2bn on insurance, R600m on tyres and R110m on lubricants and pays R7bn in salaries, this equates to an annual expenditure of approximately R24bn. According to Transaction Capital (2019), minibus taxis travel approximately 19bn kilometres per year. Therefore, the cost per year equates to approximately: R1.3/km (SANTACO, 2021)**.** This value is considered low and does not include all the wear and tear to the vehicles or the wear and tear to the infrastructure. The South African Revenue Service estimates a cost of R3.82/km for the average vehicle, the Automobile Association estimates a cost of R4.00/km – R5.00/km for minibus taxis (Quantum and Nissan). As this seems to be a more appropriate estimate, the average of **R4.5/km** is used.

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As mentioned, this proposed solution is theoretical and therefore accurate data is not available. However, as all modes will still be in operation – the cost associated with the integrated public transport system was calculated on a pro-rata basis using the costs/km and kilometres travelled per mode. This was calculated to be approximately **R4.65/km.**

4.4.2 Land-Use

As mentioned, the 'land-use' criterion was evaluated based on the value or size of land currently devoted to transportation facilities (measured in square metres).

METRORAIL

Based on PRASA's new projects listed, the existing rail service has no plans for new links in Cape Town therefore, it has been assumed that no further land will be devoted to rail. Thus, the additional value/size of land needed is zero. Cape Town has 169 kilometres of rail dedicated to passenger trips. Assuming a rail reserve of 10 metres on either side, as per the Western Cape Transport Infrastructure Act (2013), plus the average width of approximately 10 metres of rail, the approximate width is, therefore, 30 metres and the total land devoted to railway lines is approximately 5.07 square kilometres. This includes smaller stations; however, the larger stations add approximately another 1.5 square kilometres which, therefore, equates to approximately **6.57 square kilometres** of land devoted to the existing Metro Rail service.

GOLDEN ARROW BUS SERVICE

The existing **Golden Arrow Bus Services** are extensive and cover a large portion of Cape Town, as can be seen in Figure 12, it was assumed that no new stations will be constructed. Therefore, as above with rail, the value/size of land acquisition for future projects is zero. Given the existing land that had been acquired, the size of the terminals add up to approximately **0.2 square kilometres**. Bus shelters have not been taken into consideration as not all bus stops have shelters.

MYCITI SERVICE

The area of the existing red routes and major stations, as constructed for the MyCiTi service were measured and added up to approximately **0.48 square kilometres.** While there are plans to extend the service, at this stage it is unknown how much of the extension would be newly constructed road dedicated exclusively to the MyCiTi service and how many major stations will be constructed. Therefore, as with the previous modes evaluated, only the existing land devoted to MyCiTi services was taken into consideration.

MINIBUS TAXI SERVICE

As minibus taxi stops are often informal or shared with other services, and minibus taxis travel on regular roads, the only land acquired for minibus taxi services included in this study are the minibus taxi terminals, which add up to approximately **0.24 square kilometres.**

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As mentioned, this is a theoretical proposed solution and therefore accurate data is not available, however, as all modes will still be in operation – it is assumed that as with the cost, the land-use will be that of the aforementioned modes summed. I.e., MetroRail (6.57 square kilometres), Golden Arrow (0.2 square kilometres), MyCiTi (0.48 square kilometres), Minibus Taxi (0.24 square kilometres). Therefore, the land-use associated with the proposed integrated public transport system is **7.49 square kilometres.**

4.4.3 Affordability

The affordability for users was measured by the estimated cost of travel as calculated below. In order to compare each mode of public transport quantitatively, the affordability was calculated using the following equations:

$$Aff = \frac{60 \cdot p}{y_{pc}^{avg}} \cdot 100 \qquad (18)$$

$$Aff = \frac{60 \cdot p}{y_{pc}^{Q1}} \cdot 100 \qquad (19)$$

Where it is assumed that a worker requires to make 60 public transport trips per month (40 one-way trips to work and 20 miscellaneous trips); p is the public transport fare and y_{pc}^{avg} is the average per capita income and y_{pc}^{Q1} is the lowest income quintile as described in Affordability and Subsidies in Urban Public Transport: Assessing the impact of public transport affordability on subsidy allocation in Cape Town (Piek, 2017).

Using the National Household Travel Survey (Department of Transport, 2014), the average income is calculated to be approximately R10 770 per month with the lowest income quintile being approximately R1400/month. It should be noted that using the lowest income quintile is better representative of the working class who are forced into using public transport

The indirect financial benefits to users was not considered in this criterion, to avoid double-counting and vague results.

METRORAIL

The Metrorail website was consulted in order to obtain the average fare for traveling from Khayalitsha to Cape Town, which is approximately R10 per trip. Therefore, the affordability is calculated to be **6% of the average salary** calculated but **43% of the lower income quintile**.

GOLDEN ARROW BUS SERVICE

The Golden Arrow Bus Service website was consulted in order to obtain the average fare for traveling from Khayalitsha to Cape Town which is approximately R15.50 per trip. Therefore, the affordability is calculated to be **9% of the average salary** calculated but **66% of the lower income quintile**.

MYCITI SERVICE

The MyCiTi Bus Service website was consulted in order to obtain the average fare expected for traveling from Khayalitsha to Cape Town which is approximately R20.9 per trip. Therefore, the affordability is calculated to be **12% of the average salary** calculated but **90% of the lower income quintile**.

MINIBUS TAXI SERVICE

Minibus taxi users were consulted in order to obtain the average fare expected for traveling from Khayalitsha to Cape Town which was found to be approximately R25 per trip. Therefore, the affordability is calculated to be **14% of the average salary** calculated but **107% of the lower income quintile**.

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As this is a theoretical proposed solution and accurate data is not available, given though that all modes would still be in operation – for the sake of the analysis, the average fee from the aforementioned modes were consulted and the affordability was calculated to be **10% of the average salary** calculated but **77% of the lower income quintile**. It should be noted that while in a number of modes affordability is calculated at almost 10% as recommended by the National Transport White Paper Policy (1996), this is only for the average salary and trip-makers in the lower income quintile are likely forced to use the cheapest mode: trains. As the train system is on the verge of collapsing, it is worth bearing in mind that the poorest people in the country will be left without an affordable alternative.

4.4.4 Accessibility

As mentioned, the accessibility criteria refers to the Geographic Accessibility in this study, i.e., distances between activities and public transport stations / stops, as well as the NMT and parking facilities available. This will be evaluated using ArcGIS, the placement of stops and the percentage of Cape Town that is covered by the existing placement of stations / stops.

The data was imported into ArcGIS. The stations were marked as facilities and the catchment area for each facility was obtained through the data found in the National Household Travel Survey (Department of Transport, 2014), which stated the walking times to stations. The average walking time was used per mode, as well as the average walking speed of 1.36 m/s (free-flow walking speed as described in Video Data Collection Method for Pedestrian Movement Variables and Development of a Pedestrian Spatial Parameters Simulation Model for Railway Station Environments (Hermant, 2012) to obtain an average walking distance. This distance was used as the catchment area around stations and allowed for the calculation of the percentage of land covered by the service as well as Figures 18 – 21 below.

METRORAIL

Data for the location of Metrorail stations was obtained through the Department of the Premier, Directorate Provincial Spatial Information. The average walking time as stated in the National

Household Travel Survey (Department of Transport, 2014) was found to be approximately 29.3 minutes. Using the walking speed as stated above, the distance train users were willing to walk

Figure 16: Area of Cape Town covered by Metrorail stations (Source: Google Earth, 2021).

is approximately 2390 metres. Using this information, the accessibility was calculated to be approximately **11% of the City of Cape Town area**. See Figure for a visual depiction of this.

GOLDEN ARROW BUS SERVICE

Data for the location of Golden Arrow Bus Stops was obtained through the Open Data Portal. As mentioned, the average walking time as stated in the National Household Travel Survey (Department of Transport, 2014) was found to be approximately 12.4 minutes. Using the walking speed as stated, the distance Golden Arrow Bus users were willing to walk is approximately 1011 metres.

Using this information, the accessibility was calculated to be approximately **21% of the City of Cape Town area**. See Figure 16 below for a visual depiction of this.

Figure 167: Area of Cape Town covered by Golden Arrow Bus Stops (Source: Google Earth, 2021).

MYCITI SERVICE

Data for the location of MyCiTi stops and stations was obtained through the Open Data Portal. The average walking time as stated in the National Household Travel Survey (Department of Transport, 2014) was found to be approximately 23 minutes. Using the walking speed as stated above, the distance MyCiTi users were willing to walk is approximately 1878 metres. Thus, the accessibility was calculated to be approximately **7% of the City of Cape Town area**. See Figure for a visual depiction of this.

Figure 18: Area of Cape Town covered by MyCiTi Stops and Stations (Source: Google Earth, 2021).

MINIBUS TAXI SERVICE

As the minibus taxi service has both formal and informal stops and is known to stop along the route, the data for minibus taxi stops was not available. However, the data for minibus taxi routes was available through the Open Data Portal. Figure serves as a visual depiction of the minibus taxi routes in the City of Cape Town area.

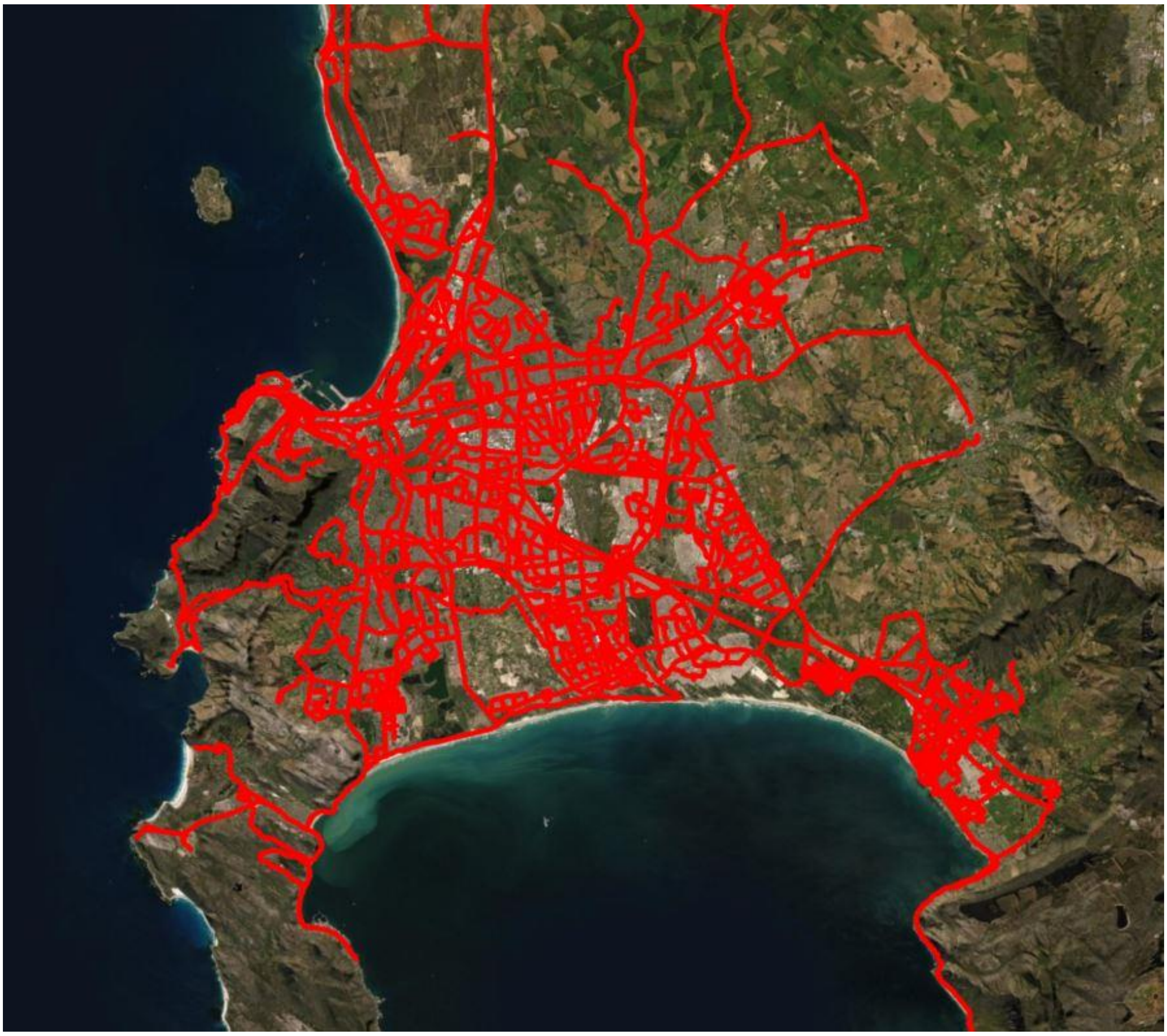

Figure 19: Minibus taxi routes in the City of Cape Town area (Source: Google Earth, 2021).

The lengths of the minibus taxi routes was calculated to be 23.7 km which covers approximately 87% of roads in Cape Town. As mentioned, the average walking time as stated in the National Household Travel Survey (Department of Transport, 2014) was found to be approximately 11.5 minutes. Using the walking speed as stated above, the distance minibus taxi users were willing to walk is approximately 938 metres. However, as minibus taxis do not stop along highways and other high-speed routes, the area covered by minibus taxis was reduced by 10%. This equated to the accessibility calculated being approximately **78% of the City of Cape Town area**.

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

Given the theoretical nature of this proposed solution, there is no accurate data is available. Thus, the assumptions made include that all modes will still be in operation and for the sake of the analysis, that the proposed integrated public transport system will, at the very least, cover the same area as covered by all the modes in existence. However, with the freeing of certain services (minibus taxis especially) additional areas may be able to gain access via the proposed feeding service.

The previously mentioned **78% coverage** provided by the minibus taxis would be the minimum covered area. It could therefore be assumed that the accessibility for the proposed integrated public transport system would be slightly higher.

4.4.5 Speed

The speed criterion refers to the speed of the vehicle, which is tied to the travel time. Therefore, this criterion was measured as User Travel Time in and out of the vehicle. Assumptions on how User Travel Time is calculated will differ for each mode and will therefore be noted when discussed in each scenario. The User Travel Time will be measured in minutes, to avoid additional errors in converting to cost. However, in order to generalise the time taken across modes, the route from Khayalitsha to Cape Town CBD was estimated using existing schedules and speeds of modes. It should be noted that time of day, month or year could affect travel time.

METRORAIL

Based on the available MetroRail schedules and not taking unpredicted delays into account, the estimated travel time in vehicle is 55 minutes, based on the available weekday morning schedule for passengers from Khayalitsha to the Cape Town CBD. According to the National Household Travel Survey (Department of Transport, 2014), the average walking time to train stations is approximately 29.3 minutes. Assuming this in both directions, the total travel time would therefore be 55 minutes + 29.3 minutes towards the station + 29.3 minutes from the station to the destination = **113.6 minutes User Travel Time.**

GOLDEN ARROW BUS SERVICE

Based on the available Golden Arrow schedules the estimated travel time in vehicle is approximately 80 minutes, assuming passengers from Khayalitsha need to be in Cape Town CBD by 07:30. A bus leaving at 06:00 is scheduled to arrive at 07:20 via the N2 Freeway (Golden Arrow Bus Service, 2019). Given the average walking time to bus stops is approximately 12.4 minutes (Department of Transport, 2014); assuming this in both directions, the total travel time would therefore be 80 minutes + 12.4 minutes towards the station + 12.4 minutes from the station to the destination = **104.8 minutes User Travel Time.**

MYCITI SERVICE

Based on the available MyCiTi schedules the estimated travel time in vehicle is approximately 51 minutes, assuming passengers from Khayalitsha need to be in Cape Town CBD by 07:30. A bus leaving at 06:12 is scheduled to arrive at 07:03 via the N2 Freeway. The next available bus will not make it to Cape Town CBD before 07:30. (MyCiTi , 2021.) As mentioned, according to the National Household Travel Survey (Department of Transport, 2014), the average walking time to bus stops is approximately 23 minutes. Assuming this in both directions, the total travel time would therefore be 51 minutes + 23 minutes towards the station + 23 minutes from the station to the destination = **97 minutes User Travel Time.**

MINIBUS TAXI SERVICE

As minibus taxis do not operate on a schedule and travel within mixed traffic, the real time Google Maps traffic data was used to estimate travel time during the morning peak hour from Khayalitsha to Cape Town assuming the passenger would need to arrive at Cape Town by 07:30. The result on average is approximately 52.5 minutes. Per the National Household Travel Survey (Department of Transport, 2014), the average walking time to bus stops is approximately 11.5 minutes. Assuming this in both directions, the total travel time would therefore be 52.5 minutes + 11.5 minutes towards the station + 11.5 minutes from the station to the destination = **75.5 minutes User Travel Time.**

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As this is a theoretical proposed solution with no accurate data available, for the sake of the analysis, it is assumed that the proposed integrated public transport system will take the average amount of time as spent by the aforementioned modes. Therefore, the total travel time would therefore be = **97.7 minutes User Travel Time.**

4.4.6 Convenience

As mentioned, the "Convenience" criteria focuses on crowd density as well as other available facilities at stations, namely, toilets, retail, seating, air-conditioning, etc. This was evaluated based on the Western Cape's respondents in the NHTS (2013). Per the NHTS (2013), the level of crowding and availability of facilities were evaluated as two separate questions using the same method of ranking from 1 to 4 as shown below:

1 = Very Satisfied

2 = Satisfied

3 = Dissatisfied

4 = Very Dissatisfied

8 = Not Applicable

9 = Unspecified

The entries who selected option 8 and 9 were removed from the analyses and average was obtained for both crowding and availability of facilities. Thereafter, the average was used to establish the Convenience.

METRORAIL

As per the NHTS (2013), the average response for rail usage was 3.09. The average response for facilities available with regards to rail was calculated to be 2.57. The average for Convenience is, therefore, calculated to be **2.83,** which places it closer to "Dissatisfied".

GOLDEN ARROW BUS SERVICE

Per the NHTS (2013), the average response for bus usage was 2.24. The average response for facilities available with regards to busses was calculated to be 2.37. The average for Convenience is therefore calculated to be **2.30,** which places it closer to “Satisfied”.

MYCITI SERVICE

According to the NHT Survey, the average response for BRT usage was 1.85. The average response for facilities available with regards to BRT was calculated to be 1.68. The average for Convenience is therefore calculated to be **1.77,** which places it closer to “Satisfied”.

MINIBUS TAXI SERVICE

As per the NHT Survey, the average response for minibus taxi usage was 2.49. The average response for facilities available with regards to BRT was calculated to be 2.44. The average for Convenience is, therefore, calculated to be **2.47,** which places it closer to “Satisfied”.

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As this is a theoretical proposed solution with no accurate data available, for the sake of analysis, it is assumed that the proposed integrated public transport system would have the best convenience rating as the existing options would still exist and theoretically, users will be able to navigate from one mode to the other seamlessly using one public transport card. Therefore, the value assigned for convenience is **1.**

4.4.7 Reliability

The “Reliability” criterion refers to the punctuality of the public transport mode. This was evaluated based on NHTS (2013). The questions factored into the final result were based on Frequency, Punctuality and Overall Service. Each question was evaluated using the same method of ranking from 1 to 4 as previously described in Section 4.4.6.

METRORAIL

Frequency: The average obtained for MetroRail’s frequency was found to be 2.3.

Punctuality: The average obtained for MetroRail’s punctuality was found to be 2.6.

Overall Service: The average obtained for MetroRail’s overall service was found to be 2.49.

Therefore, the Reliability was calculated to be **2.49,** which places it almost halfway between Satisfied and Dissatisfied.

GOLDEN ARROW BUS SERVICE

Frequency: The average obtained for Golden Arrow Bus frequency was found to be 2.08.

Punctuality: The average obtained for Golden Arrow Bus punctuality was found to be 2.1.

Overall Service: The average obtained for Golden Arrow Bus overall service was found to be 2.11.

Therefore, the Reliability was calculated to be **2.10,** which places it much closer to Satisfied than Dissatisfied.

MYCITI SERVICE

Frequency: The average obtained for MyCiTi Bus frequency was found to be 1.86.

Punctuality: The average obtained for MyCiTi Bus punctuality was found to be 1.9.

Overall Service: The average obtained for MyCiTi Bus overall service was found to be 1.43.

Therefore, the Reliability was calculated to be **1.73,** which places it much closer to Satisfied than Very Satisfied.

MINIBUS TAXI SERVICE

Frequency: The average obtained for minibus taxi frequency was found to be 2.13.

Punctuality: This criterion does not apply to minibus taxis as no schedules are posted.

Overall Service: The average obtained for minibus taxi overall service was found to be 2.35.

Therefore, the Reliability was calculated to be **2.24,** which places it much closer to Satisfied than Dissatisfied.

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As this is a theoretical proposed solution with no accurate data available, for the sake of this analysis, it is assumed that the proposed integrated public transport system would have the best reliability rating as the existing options will still exist and theoretically, users should be able to navigate from one mode to the other seamlessly using one public transport card should a mode be delayed/out-of-order. Therefore, the value assigned for reliability is **1.**

4.4.8 Environment

As mentioned, "Environmental Impacts" refer to the impacts the various modes of transportation have on the environment. However, information for Metrorail, Golden Arrow busses, MyCiTi busses and minibus taxis was not available, therefore, generic figures were used based on the passenger rail, busses, BRT, and minibus taxi information available.

METRORAIL

A study from the European Environment Agency in 2014, estimates **14 grams** of CO_2 per passenger kilometre for rail (European Environment Agency, 2015).

GOLDEN ARROW BUS SERVICE

The study mentioned above estimates **68 grams** of CO_2 per passenger kilometre for busses (European Environment Agency, 2015).

MYCITI SERVICE

Standard busses are, generally, used for the MyCiTi service and therefore, the same figures as obtained for the Golden Arrow Buses were used. Therefore, the CO2 per passenger kilometre is **68 grams** (European Environment Agency, 2015).

MINIBUS TAXI SERVICE

A van is estimated to emit **55 grams** of CO2 per passenger kilometre (European Environment Agency, 2015).

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As mentioned, this is a theoretical proposed solution and, therefore, accurate data is not available, however, as all modes will still be in operation – the emissions associated with the integrated public transport system was calculated on a pro-rata basis using the CO_2 per passenger kilometres and kilometres travelled per mode. Therefore, the value assigned for fuel consumption is **54 grams** of CO_2 per passenger kilometre**.**

4.4.9 Safety

The "Safety" criterion is two-fold, referring to both the safety and security of the user, as well as of the public transport mode. This will be evaluated based on the NHTS (2013). The questions factored into the final "Safety" result were based on Security on the walk to or from the Stop/Station, Security at the Stop/Station, Security on the Vehicle and Accidents. Each question was evaluated using the same method of ranking from 1 to 4 as described in Section 4.4.6.

METRORAIL

Security on Walk to or from Stop/Station: The average obtained for the security of passengers while walking to or from train stations was found to be 2.71.

Security at the Stop/Station: The average obtained for the security at stops/stations while waiting for trains was found to be 2.3.

Security on the Vehicle: The average obtained for the security of the passenger on the train was found to be 2.54.

Accidents: The average obtained for accidents involving trains is 2.2.

Therefore, the overall "Safety", was found to be **2.44**, which places it almost halfway between Satisfied and Dissatisfied (NHTS, 2013).

GOLDEN ARROW BUS SERVICE

Security on walk to or from Stop/Station: The average obtained for the security of passengers, while walking to or from bus stations was found to be 2.31.

Security at the Stop/Station: The average obtained for the security at stops/stations while waiting for buses was found to be 2.37.

Security on the Vehicle: The average obtained for the security of the passenger on the bus was found to be 2.23.

Accidents: The average obtained for accidents involving buses is 2.12.

Therefore, the overall "Safety", was found to be **2.26**, which places it closer to Satisfied than Dissatisfied (NHTS, 2013).

MYCITI SERVICE

Security on Walk to or from Stop/Station: The average obtained for the security of passengers while walking to or from MyCiTi stations was found to be 2.

Security at the Stop/Station: The average obtained for the security at stops/stations while waiting for MyCiTi buses was found to be 1.81.

Security on the Vehicle: The average obtained for the security of the passenger on the MyCiTi bus was found to be 2.23.

Accidents: The average obtained for accidents involving MyCiTi buses is 1.93.

Therefore, the overall "Safety", was found to be **1.86**, which places it much closer to Satisfied than Very Satisfied (NHTS, 2013).

MINIBUS TAXI SERVICE

Security on Walk to or from Stop/Station: The average obtained for the security of passengers while walking to or from minibus taxis were found to be 2.33.

Security at the Stop/Station: The average obtained for the security at stops/stations while waiting for minibus taxis were found to be 2.26.

Security on the Vehicle: The average obtained for the security of the passenger on the minibus taxis were found to be 2.31.

Accidents: The average obtained for accidents involving minibus taxis were 2.5.

Therefore, the overall "Safety", was found to be **2.35**, which places it closer to Satisfied than Dissatisfied (NHTS, 2013).

PROPOSED INTEGRATED PUBLIC TRANSPORT SYSTEM

As this is a theoretical proposed solution with no accurate data available, for the sake of analysis, it is assumed the proposed integrated public transport system will take the average of the aforementioned modes for reliability. Therefore, the value assigned for “Safety” is **2.23.**

5. ANALYSIS AND RESULTS

As previously mentioned, two MCDA methods were used in order to evaluate and compare the results of different methods. The chosen criteria were weighted using the AHP method, which will be discussed in the next section. Thereafter, the weighted and unweighted criteria was used in MCDA using the SAW method. The weighted and unweighted criteria was then used in MCDA using the EVAMIX method.

The goal is to evaluate and compare public transport projects based on the chosen criteria and alternatives available as shown in Figure 20.

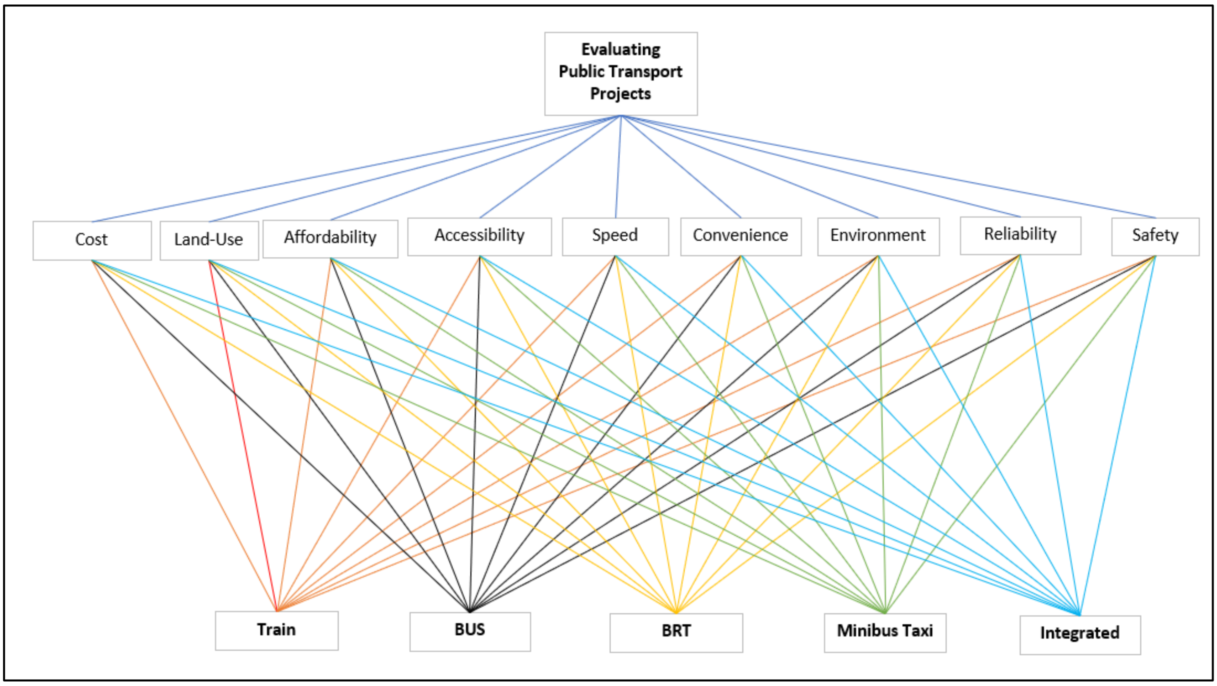

Figure 20: Diagram showing the available alternatives and chosen criteria

5.1. Weighting of Criteria

As discussed in Section 3.1.2.1 the method for AHP Analysis is explained and was implement in the weighting of the chosen criteria. Using Table 2: Responses of relative importance based on Saaty's nine-point scale (Source: *Berritella* et al., 2009) as a guide, a pair-wise comparison survey was sent to ten participants. The participant group consisted of:

- Five engineers from the Department of Transport at the Western Cape Government.
- Four engineers from the Department of Transport at the City of Cape Town.
- Ten engineers working in the Transport and Traffic Engineering industry – including engineers from UDS Africa, SMEC and Zutari.
- Three academics working in Transport and Traffic Engineering – one academic from the University of Cape Town, one academic from Stellenbosch University and one from the Cape Peninsula University of Technology.
- Two project managers/planners from Zutari.
- One Environmental Practitioner from BRAAF Environmental Practitioners.

Separate to this, the survey was opened to members of the public who use public transport in order to establish whether the public's weightings would differ vastly from that of the specialists (working in private and public institutions). A copy of the survey is attached in Appendix D.

The survey comprised of 28 questions comparing the chosen criteria and participants were instructed to slide the centre marker towards the criteria they prefer in their own professional capacity. The closer to the criterion the marker was moved, the more preferred the criterion was in comparison to the opposing criterion as per Saaty's nine-point scale (1980) as previously shown in Table 2: Responses of relative importance based on Saaty's nine-point scale (Source: Berritella *et al*., 2009)

The results were collated and the mean ratings for were obtained as shown in Table 6: Mean values assigned via survey results and Table 7: Mean values assigned via survey results for the general public.

Table 6: Mean values assigned via survey results for specialists (private and public specialists combined)

Criteria	Cost	Land-Use	Afford-ability	Access-ibility	Speed	Con- & Reliability	Enviro-nment	Safety & Security
Cost	1	1.9385	0.95831	0.51249	2.20276	1.305590	2.65162	0.7736
Land-Use	0.5158	1	1.49413	1.24292	2.71787	1.176673	1.91870	0.48523
Affordability	1.0434	0.6692	1	1.91014	4.36231	2.422222	3.80193	0.85645
Accessibility	1.9512	0.8045	0.52352	1	4.36231	2.913043	3.4168	0.66901
Speed	0.4539	0.3679	0.22923	0.22923	1	0.854520	1.70614	0.29440
Convenience	0.7659	0.8498	0.4128	0.34328	1.17024	1	3.23326	0.57046
Environment	0.3771	0.5211	0.26302	0.29266	0.58611	0.309284	1	0.33609
Safety	1.2925	2.0608	1.16760	1.49473	3.39662	1.752963	2.97535	1

Table 7: Mean values assigned via survey results for the general public

Criteria	Cost	Land-Use	Afford-ability	Access-ibility	Speed	Con- & Reliability	Environ-ment	Safety & Security
Cost	1	1.6924	1.07873	0.811640	1.45079	0.7574603	0.92592	0.754497
Land-Use	0.5908	1	1.61544	0.686349	2.54793	0.9551322	1.2226	0.401904
Affordability	0.9270	0.6190	1	1.749629	5.26666	1.299682	2.55978	0.775238
Accessibility	1.2320	1.4569	0.57154	1	5.07407	3.6857142	3.37333	1.264973
Speed	0.6892	0.3924	0.18987	0.197080	1	0.4455026	0.39132	0.812063
Convenience	1.3202	1.0469	0.76941	0.271317	2.24465	1	1.60740	0.401904
Environment	1.08	0.8178	0.39065	0.296442	2.55543	0.6221198	1	0.732910
Safety	1.3253	2.4881	1.28992	0.790530	1.23143	2.4881516	1.36442	1

The AHP method resulted in the following weights for the specialist as well as the neutral/academic opinion – where the weights are equal as the academic opinion is assumed to be unbiased:

Table 8: Specialist, Academic (Unbiased) and General Public Criteria Weighting

Criteria	Specialist Weight	Public Weight	Academic (unbiased) Weight
Cost	0.14	0.12	0.13
Land-Use	0.13	0.11	0.13
Affordability	0.18	0.16	0.13
Accessibility	0.17	0.20	0.13
Speed	0.06	0.05	0.13
Convenience & Reliability	0.09	0.10	0.13
Environment	0.05	0.09	0.13
Safety & Security	0.19	0.16	0.13
Sum	1	1	1

The Consistency Ratio was calculated using the equation mentioned in Section 3.1.2.1 along with Figure 6: Random Consistency Index (Source: Saaty, 1980) and was found to be 0.04 for the specialist weighting and 0.06 for the general public, both of which is less than 0.1 and therefore considered acceptable.

5.2. Weighted and Unweighted MCDA using SAW Method

In order to determine the effects that weighting criteria have on the outcome, both weighted and unweighted analyses were performed. A matrix was constructed to include all the alternatives and the values/quantities assigned to each criteria as shown below:

Table 9: Decision Matrix showing alternatives and criteria

Alternatives / Criteria	Cost (R/km)	Land-Use (area sqm km)	Afford- (%)	Access- (%)	Speed (mins)	Conv- & Reliability (Rating)	Enviro- (CO2/ pass.km)	Safety (Rating)
Train	21.78	6.57	43	11	113.6	2.66	14	2.44
Bus	25.65	0.2	66	21	104.8	2.2	68	2.26
BRT	85.2	0.48	90	7	97	1.75	68	1.86
Minibus Taxi	4.5	0.24	107	78	75.5	2.35	55	2.35
Integrated	4.65	7.49	77	100	97.7	1	54	2.23

The decision matrix was then normalised using the method described in Simple Additive Weighting (SAW) Method and is shown below:

Table 10: Normalised Decision Matrix as per SAW Method

Alternatives / Criteria	Cost (R/km)	Land-Use (area sqm km)	Afford- (%)	Access- (%)	Speed (mins)	Conv- (Rating)	Enviro- (CO2/ pass.km)	Safety (Rating)
Train	0.21	0.03	1.00	0.11	0.66	0.38	1.00	0.76
Bus	0.18	1.00	0.65	0.21	0.72	0.45	0.21	0.82
BRT	0.05	0.42	0.48	0.07	0.78	0.57	0.21	1.00
Minibus Taxi	1.00	0.83	0.40	0.78	1.00	0.42	0.25	0.79
Integrated	0.97	0.03	0.56	1.00	0.77	1.00	0.26	0.83

Thereafter the final score per alternative was calculated using the sum of the values in the normalised matrix multiplied by the weights calculated. The results and rankings are as shown below where green represents the most preferable option and red represents the least preferable option:

Table 11: SAW Method Results and Ranking

Alternatives / Criteria	**Score (Specialist)**	**Ranking**	**Score (Public)**	**Ranking**	**Score (Unweighted)**	**Ranking**
Train	0.62	4th	0.60	4th	0.64	4th
Bus	0.68	3rd	0.62	3rd	0.66	3rd
BRT	0.582	5th	0.527	5th	0.57	5th
Minibus Taxi	0.836	2nd	0.78	2nd	0.81	1st
Integrated	0.84	1st	0.814	1st	0.80	2nd

As can be seen in the results above, the specialist and public weightings result in the same ranking of alternatives, whereas the unweighted analysis ranks slightly differently, however, the worst alternative is common amongst all three analyses.

5.3. Weighted and Unweighted MCDA using EVAMIX Method

As with the previous method, in order to distinguish the effect of the weights applied, both the weighted and unweighted analyses were performed using the EVAMIX method. Similarly, to the above, the first step is compiling the matrix as shown in Table 9: Decision Matrix showing alternatives and criteria. However, differing from the above, the matrix was normalised using a slightly different equation. This equation is described in 3.1.2.3 and two different equations were used as the data was separated into beneficial and non-beneficial. It was also determined that all data was cardinal.

The normalised matrix is shown in Table 14.

Table 12: Normalised Matrix for EVAMIX Method

Alternatives / Criteria	Cost (R/km)	Land-Use (area sqm km)	Land-Use (NMT)	Afford- (%)	Access- (%)	Speed (mins)	Conven- & Reliability (Rating)	Enviro- (CO2/ pass.km)	Safety (Rating)
Train	0.79	0.13	1.00	1.00	0.04	0.00	0.00	1.00	0.00
Bus	0.74	1.00	1.00	0.64	0.15	0.23	0.28	0.00	0.31
BRT	0.00	0.96	1.00	0.27	0.00	0.44	0.55	0.00	1.00
Minibus Taxi	1.000	0.99	1.00	0.00	0.76	1.00	0.18	0.24	0.16
Integrated	0.998	0.00	1.00	0.47	1.00	0.42	1.00	0.26	0.36

The dominance and standardized dominance scores were then calculated for each pair of alternatives as shown below:

Table 13: Standardized Dominance Scores for Each Pair of Alternatives (Specialist Weighted)

Alternatives	Dii'	**Alternatives**	Dii'
Train/Bus	0.26	BRT/MBT	0.34
Train/BRT	0.33	BRT/Integrated	0.17
Train/MBT	0.17	MBT/Train	0.83
Train/Integrated	0.00	MBT/Bus	0.59
Bus/Train	0.74	MBT/BRT	0.66
Bus/BRT	0.58	MBT/Integrated	0.33
Bus/MBT	0.41	Integrated/Train	1.00
Bus/Integrated	0.24	Integrated/Bus	0.76
BRT/Train	0.67	Integrated/BRT	0.83
BRT/Bus	0.42	Integrated/MBT	0.67

Table 14: Standard Dominance Scores for Each Pair of Alternatives (Public Weighting)

Alternatives	Dii'	**Alternatives**	Dii'
Train/Bus	0.37	BRT/MBT	0.14
Train/BRT	0.42	BRT/Integrated	0.08
Train/MBT	0.05	MBT/Train	0.95
Train/Integrated	0.00	MBT/Bus	0.82
Bus/Train	0.63	MBT/BRT	0.86
Bus/BRT	0.54	MBT/Integrated	0.45
Bus/MBT	0.18	Integrated/Train	1.00
Bus/Integrated	0.13	Integrated/Bus	0.87
BRT/Train	0.58	Integrated/BRT	0.92
BRT/Bus	0.46	Integrated/MBT	0.55

Table 15: Standardized Dominance Scores for Each Pair of Alternatives (Unweighted)

Alternatives	Dii'	Alternatives	Dii'
Train/Bus	0.27	BRT/MBT	0.71
Train/BRT	0.00	BRT/Integrated	0.96
Train/MBT	0.21	MBT/Train	0.79
Train/Integrated	0.46	MBT/Bus	0.56
Bus/Train	0.73	MBT/BRT	0.29
Bus/BRT	0.23	MBT/Integrated	0.75
Bus/MBT	0.44	Integrated/Train	0.54
Bus/Integrated	0.69	Integrated/Bus	0.31
BRT/Train	1.00	Integrated/BRT	0.04
BRT/Bus	0.77	Integrated/MBT	0.25

The appraisal score was then calculated for each alternative. The appraisal score depends on the overall dominance of it and this score was used for the final ranking shown below:

Table 16: Final Ranking of Alternatives using the EVAMIX method (Weighted and Unweighted)

Alternatives / Score	Specialist Score	Ranking	Public Score	Ranking	Academic Score	Ranking
Train	0.10	5th	0.16	3rd	0.049	4th
Bus	0.18	3rd	0.09	4th	0.08	3rd
BRT	0.11	4th	0.03	5th	0.052	5th
Minibus Taxi	0.29	2nd	0.27	2nd	0.60	2nd
Integrated	0.99	1st	1.77	1st	0.96	1st

As can be seen in the results in Table 18, all three weightings result in slightly different rankings, however, the best alternative is common amongst them.

5.4. Aggregation of Results

The following rankings were achieved using different methods and weights:

Alternatives	SAW (Specialist)	SAW (Public)	SAW (Academic)	EVAMIX (Specialist)	EVAMIX (Public)	EVAMIX (Academic)
Train	4th	4th	4th	5th	3rd	4th
Bus	3rd	3rd	3rd	3rd	4th	3rd
BRT	5th	5th	5th	4th	5th	5th
Minibus Taxi	2nd	2nd	1st	2nd	2nd	2nd
Integrated	1st	1st	2nd	1st	1st	1st

As mentioned, three aggregation methods were used to establish a common ranking between the results above. The rankings as per the aggregation methods are shown below:

Table 17: Aggregation Ranking Results

Alternatives	BORDA	COPELAND	ARP
Train	4th	4th	4th
Bus	3rd	3rd	3rd
BRT	5th	5th	5th
Minibus Taxi	2nd	2nd	2nd
Integrated	1st	1st	1st

As seen in Table 19, while there are slight differences in the rankings, it is clear that the Integrated Transport System is considered the ‘best’ existing option and the current BRT system is considered the worst.

6. DISCUSSION

Two different MCDA methods were used and three separate weightings (specialist, public transport users and neutral/unweighted) in order to test the sensitivity between methods, as well as weighting. The AHP method used to establish weightings was simple to use for both the planners/engineers and the general public, as the consistency ratio was under 10% it can, therefore, be concluded that the general public were consistent in their answers thereby understanding the questions and the survey.

The AHP method is a useful tool for establishing weights in public transport planning as a variety of stakeholders are and should be involved in public transport planning long before implementation. The AHP method lends itself to including an unlimited number of stakeholders from different backgrounds. The AHP method used in this research paper was setup using Microsoft Excel and while the data input is heavy, it is a cost-efficient and simple solution. Software programmes specialising in AHP exist for larger surveys. Upon closer inspection, the preferences between stakeholders could be seen. 'Cost' was weighted higher by specialists than public transport users. Surprisingly, 'Affordability' was weighted higher by specialists than public transport users. The highest weighted criterion by specialists was 'Safety & Security', whereas for the public transport users, 'Accessibility' was heavily weighted. In both cases, 'Speed' and 'Environmental' were weighted as the least important factors.

However, it should be noted that, due to the nature of the survey (pairwise comparisons), the number of questions were based on the number of criteria used. Four criteria would result in six questions, five criteria in ten questions, etc. In this research paper, eight criteria were used, which resulted in twenty-eight questions. It is recommended that, in order to keep a consistency ratio under the required 10%, the number of criteria is kept under nine.

The SAW method was easy to use and so to the setup on a Microsoft Excel spreadsheet. The results for the weighted (both specialist and general public transport users) concluded in the same rankings, i.e., from best to worst, Integrated Transport System (theoretical), Minibus Taxis, Busses, Trains, and BRT. Whereas the unweighted rankings were ordered slightly differently; it started with Minibus Taxis, it still ended with BRT.

The EVAMIX method was slightly more complicated than the SAW method but could also be setup using Microsoft Excel. While ordinal data was not used in this research, it could be a powerful tool used in public transport planning. That said, it should be noted that there are a number of ways to standardise the data, each of them providing a slightly different result. Only one of them were used in this work.

All three weightings resulted in the same 'best' option: the Integrated Transport System (theoretical). However, the results differed on everything else, with two out of the three results agreeing that the 'worst' option would be the BRT System. In all cases, aggregation methods were used to finalise the results. The Borda, Copeland and ARP method agreed on the Integrated Transport System (theoretical) being the best option and BRT System being the worst.

After aggregation there is no confusion reading the results and establishing the best alternative which, as can be seen in Table 17 is (1st) Integrated Transport System, (2nd) Minibus Taxis, (3rd) Bus, (4th) Trains and (5th) BRT.

What should be noted in all methods used is the sensitivity of the data used for the criteria values and in this case. Secondary data was used for the sake of this analyses and to establish the ‘best’ and ‘worst’ investment options in public transport, primary data would need to be collected.

7. CONCLUSIONS

Public transport projects often need a large investment in order to implement or upgrade infrastructure and facilities. The mode being implemented or upgraded is often determined using the Cost-Benefit analysis which has been proved to provide justifiable solutions, however, another method of evaluation is possible – the multi-criteria decision analysis.

1. What are the most common methods of MCDA currently being used in public transport evaluation?

The top three most popular methods are AHP/ANP (Analytic Hierarchy/Network Process) – often used in combination with another method, such as the Evaluation of Mixed Data method (EVAMIX), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and Fuzzy Set – often used as a part another method, such as the Simple Additive Weighting Method (SAW, also known as Weighted Sum). The SAW method appeals to the school of thought of unified scores across alternatives, applying weighting and sums the result per alternative. The EVAMIX method appeals to the second school of thought takes it one step further and after the unification of scores, the alternatives are compared pairwise (Vanderschuren & Frieslaar, 2008).

In this research paper, two methods were implemented: the Simple Additive Weighted Method (SAW) and the Evaluation of Mixed Data method (EVAMIX). Both methods were used in conjunction with the Analytical Hierarchy Process (AHP). The methods were applied to determine the best and worst existing modes of public transport in Cape Town. Therefore, the following modes were compared in the analysis, exclusively – i.e. Assumed to be running on its own: Trains (MetroRail), BRT (MyCiTi), Bus (Golden Arrow) and minibus taxis. In addition to this, a theoretical fifth option on integrating the abovementioned modes was included.

2. How did the opinion of the general public differ from that of engineers and government employees regarding the importance of criteria?

Engineers and other specialists working within the transport sector (public and private) were approached to participate in the survey which comprised of a pairwise comparison of the identified criteria. In addition to this, academics within the transport sector were also approached, as well as the general public who have used public transport in Cape Town.

The AHP method was used to determine the weights from the surveys.

The general public rated 'Accessibility' as the top criteria, whereas the specialists in the private sector and public sector agreed that 'Safety & Security' is the top criteria, which is the second most important criteria to the general public. Tied for the second most important criteria, the general public voted for 'Affordability'. the private sector specialists agreed, whereas the public sector rated 'Accessibility' as the second most important criteria. In third place, the general public, as well as the specialists in the public sector agreed that 'Cost' is important, whereas the private sector rated 'Accessibility' as the third most important criteria. While the three perspectives differed, it can be seen that the top four criteria across the board, in no particular order are ‘Accessibility’, ‘Affordability’, ‘Safety & Security’ and ‘Cost’.

On the other end of the scale, the lowest weighted criteria were ‘Speed’ for the general public and ‘Environmental’ for engineers in both the public and private sector. The engineers in both the public and private sector agree that ‘Speed’ is the second least important criteria and conversely, the general public has ‘Environmental’ listed as the second least important criteria. All three perspectives agree that ‘Convenience & Reliability’ is the third least important criteria. Therefore, it can be seen that the bottom three criteria, in no particular order is ‘Speed’, ‘Environmental’ and ‘Convenience & Reliability’.

3. How did the results differ between the methods of MCDA?

The weights as obtained through AHP were used in the SAW method, the results indicated that the mode that should be invested in, from best to worst, is the Integrated Transport System, Minibus Taxi, Bus, Trains and BRT for both weighted scenarios. The unweighted scenario differed slightly and resulted in Minibus Taxis being the best option for investment, followed by the theoretical Integrated Transport System, Bus, Trains and lastly, the BRT.

The EVAMIX method was then used with the following results: best choice (specialist, general public and academic perspective): Integrated Transport System (theoretical), followed by Minibus Taxis. The specialist and academic perspective agreed that Busses would be the best third investment option, whereas the general public preferred Trains. Two out of the three perspectives (public and academic) agreed that the BRT is the least desirable alternative for further investment.

Therefore, it can be seen that the results of two different MCDA methods differed slightly and the results within the same methods differed slightly between perspectives. In order to consolidate the differences, aggregation methods were applied.

4. How did the results differ for different levels of aggregation?

Three methods of aggregation were applied, Copeland, Borda and the Average Ranking Procedure. While there were slight differences in the results of the MCDA, the aggregation resulted in the same ranking across all three methods.

The final listing is as follows: 1st – Integrated Transport System, 2nd – Minibus Taxi, 3rd – Bus, 4th – Trains and 5th – BRT.

It can, therefore, be concluded that both the SAW and EVAMIX methods are suitable for use in public transport project evaluation to complement the existing methods of using a cost-benefit analyses.

5. Lastly, what time period should be evaluated in the implementation of public transport projects?

It should be noted that some impacts occur in the short term, and other’s long-term, therefore, a life-cycle evaluation of public transport is necessary. The impacts can be evaluated in the stages discussed by Chen (2014). The first stage is identified as the stage before the transport service is active, these include land use/re-development, property value and townscape image. These impacts are not caused by usage, they are impacted just by the planned infrastructure.

The second stage is identified as the stage once the transport system is activated. There are new origins and destinations. Four kinds of impacts have been identified, those include, growth of consumer services, business operation and location, agglomeration effects and labour market and employment. Those effects are seen as medium- to long-term effects. The third stage is identified as the long-term stage, wider impacts that affect the urban spatial infrastructure is seen, as well as rebalancing of transport habits. However, there are arguments based on "How long is long term?" as collecting and comparing data over a long period is challenging.

8. RECOMMENDATIONS

It is recommended that when the evaluation is performed, primary data be collected as far as possible to ensure that the results are accurate. Generally, public transport projects are evaluated by or by the order of the City of Cape Town or Western Cape Government and should this be the case, access to more accurate data should be possible.

It is further recommended that should an integrated transport system be considered; that the analysis is re-evaluated with the detailed design of the integrated transport system which would provide more precise data and may change the results. This investigation considered annual maintenance and operations costs, for further research, it is recommended that in the use of multi-criteria decision analyses involving public transport projects, the lifecycle of public transport projects be considered.

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10. APPENDICES

Appendix A: Example of the Use of CBA in Transportation Evaluation

Example 1: Cost/Benefit Analysis for CityExpress in Keene, New Hampshire (New Hampshire Department of Transportation; Home Healthcare, Hospice and Community Services; SWRPC, 2001)

The example investigates increasing the existing three-route public transportation route, operating from 06:30 – 19:00 six days a week to a five-route system with expanded hours and service seven days a week or more.

Benefits included in analysis:

- Social and environmental benefits,
- Local and regional economic benefits, and
- Transit user benefits.

Cost included in analysis:

- Transit operating costs,
- Transit capital costs, and
- Cost associated with changing regular operating procedures.

Social and environmental benefits were measured as follows:

Air Pollution: Air pollution was measured in terms of reductions of miles travelled by private vehicles ($0.069 per mile of auto travel reduced), as travellers are assumed to switch to using the introduced public transport option.

Water Pollution: Water pollution was measured in terms of reductions of miles travelled by private vehicles relating to oil spills ($0.01 per mile of auto travel reduced) as travellers are assumed to switch to using the introduced public transport option.

Safety Benefits: Safety was measured in the reduction in accidents of private vehicles versus public transport ($0.062 for each mile shifted from driving to transit).

Local and Regional Economic Benefits were measured as follows:

Reduced Roadway and Facility Investments: The benefits of reduced roadway and facility investments were measured on the basis that should travellers opt to use public transport, there will be less wear and tear on public roads which would lead to less need for maintenance. The shift from private to public transport will also reduce congestion, thereby reducing the need for expansion.

In addition to this, as travelling by public transport has been deemed safer than that by private vehicle, there is less demand on law enforcement and medical services.

In total, the calculated benefits have been estimated to an average of $0.30 per mile assuming that each bus removes an average of twenty-five cars from the road.

Other Avoided Public Expenditures: It had been shown that increased transit service reduces the cost to administer certain major federal programmes, such as Medicare, Medicaid, Food Stamps and Unemployment Compensation. Each dollar invested reduces the cost by an average of $0.60.

Employment Benefits & Increased Local Expenditures: The net result of the employment benefits and increased local spending related to increased transit service was estimated to be a return of $0.75 on every dollar invested in a transportation system.

Federal Subsidies: Federal operating and capital subsidies can be seen as a benefit to the city as these monies would be spent elsewhere without CityExpress. The Federal subsidy benefit is the total of the funding support for operating and capital investments.

Transit User Benefits were measured as follows:

Transit vs. Automobile Savings: It was assumed that 75% of new users captured by the increased public transport would be current private car users. Daily driving costs (from use of private vehicles) was compared to daily transit costs (public transport), the difference was multiplied by 75% of the projected ridership.

Mobility: The quantified benefit from improved mobility is determined by calculating the average consumer surplus (i.e., the net value of transportation to an individual) per transit trip across all income levels and then subtracting the public expenditures required to operate a transit system. This equated to a net economic benefit of $2.45 per transit trip.

Costs were calculated as follows:

Transit Operating Costs: This includes salaries of bus drivers, mechanics, management officials, maintenance and upkeep.

Capital Costs: Transit capital costs include the purchase of vehicles and other items such as shelters and stops.

Cost associated with changing regular operating procedures: Changes in municipal operating procedures are required to encourage a successful shift from private vehicle usage to public transport.

Using the information above, as well as the ridership projected, the following Cost and Benefit Summary was calculated for the number of routes from one route to ten routes (New Hampshire Department of Transportation; Home Healthcare, Hospice and Community Services; SWRPC, 2001):

Table 18: Cost and Benefit Summary

Cost and Benefit Summary

# Routes	Costs	Benefits	Difference	Benefit/Cost
1	$165,600	$428,544	$262,944	2.59
2	$270,000	$661,170	$391,170	2.45
3	$330,000	$800,259	$470,259	2.43
4	$390,000	$932,049	$542,049	2.39
5	$450,000	$1,058,001	$608,001	2.35
⬇	⬇	⬇	⬇	⬇
10	$750,000	$1,645,429	$895,429	2.19

(Source: (New Hampshire Department of Transportation; Home Healthcare, Hospice and Community Services; SWRPC, 2001)

The conclusion was, therefore, that the cost to benefit ratio for the five-route system is 2.35, which means that for every dollar spent on transit, $2.35 may be returned in the form of economic, social and environmental benefits.

Example 2: High Speed Two (HS2) linking London to Manchester and Leeds, via Birmingham

HS2 has been split into three phases:

- Phase 1: From London Euston to Birmingham Curzon Street with intermediate stations in West London and at Birmingham Airport,
- Phase 2a: From the West Midlands to Crewe and,
- Phase 2b: Comprising an eastern leg from the West Midlands to Leeds New Lane with intermediate stations in the East Midlands and South Yorkshire and a western leg from Crewe to Manchester with an intermediate station at Manchester Airport.

The introduction of this HS2 is expected to reduce travel time by 49 minutes and connect to existing rail lines (Thepeoplepartnership, 2011). Proponents of the project also say it will improve transport times, create jobs and help the country's economy. (Hirst, 2021)

Non-monetary benefits include environmental impacts where advocates claim the line will provide a cleaner way to travel. However, critics are concerned over the potential damage to of construction to the ancient woodlands. Other non-monetary impacts include housing that will need to be removed and property and landowners that will need to be compensated based on proximity to the railway (Hirst, 2021).

The monetised and non-monetised impacts of HS2 are shown below in Table 19 as well as which impacts were included in the BCR (benefit-cost ratio).

Table 19: Monetised and non-monetised impacts of HS2

Initial BCR: Monetised impacts	Adjusted BCR: Monetised impacts	Monetised impacts not	Non-monetised qualitative impacts
Travel Time Savings (in-vehicle, walk and	Agglomeration	Landscape	Townscape and Landscape Heritage

Crowding Noise	Labour Supply Impacts		Biodiversity
Carbon Impact	Imperfect Competition		Water
Accidents			Environment
Infrastructure			Severance
Indirect Tax Revenue			Physical Activity
Reliability			Journey Quality
Air Quality			Option Values Security
Access and Egress			
Operational Revenues			

It is estimated that the full HS2 network will cost £72 billion to £98 billion compared to the initial cost estimate of £37.5 billion. The cost-benefit ratio using the new estimated costs is between 1.3 and 1.5 which represents 'low-medium' value for money.

The cost estimate difference is due to underestimating the complexity of the project as well as the scope changing between 2017 and 2021. (Hirst, 2021)

The alternative analysed was a conventional railway, however the results showed that HS2 is estimated to cost 9% more and considering the economic benefits to be gained from shorter travelling times and improving interconnectivity between cities it was deemed that HS2 is the better alternative. (Hirst, 2021).

Appendix B: Example of the Use of AHP in Transportation Evaluation

Example: Analytic Hierarchy Process assessment for potential multi-airport systems _ The case of Cape Town (Zietsman & Vanderschuren, 2014)

The example investigates the analysis performed where a potential second airport was proposed in Cape Town.

The criteria identified to be included in the analysis are listed below:

1. The strength of an airport to generate air transport demand which includes attributes such as socio-economic indicators and the attractiveness of the region in terms of tourism,
2. The operational and economic characteristics of a candidate airport, including the airport size, quality of access, quality of service, cost of service, and
3. The environmental constraints, which included the attributes of aircraft noise and land uptake.

The abovementioned criteria were then grouped into five clusters, namely:

1. Socio-economic development: referring to progress made in achieving socio-economic goals of the community with a focus on improving the lives of the poor,
2. Spatial and Urban planning: referring to the balanced distribution of people, activities and spaces of various scales,
3. Transport Improvement, Efficiency and Provision: referring to mobility, accessibility and movement of goods and services,
4. Environmental Preservation: referring to protection and/or restoration of wildlife and natural resources, and
5. Financial Viability: Sufficient income to cover costs.

The criteria were weighted through the surveying of stakeholders. Using the weights achieved, the AHP method was followed and resulted in a second airport being undesirable at this stage. The research continued through to performing a sensitivity analysis to conclude at which stage of passenger demand a second airport would result in a positive result.

Appendix C: Example of the Use of SAW and EVAMIX in Transportation Evaluation

Example: Assessment of the Improvement Strategies for the N1 Corridor Between Bellville and Cape Town (Vanderschuren & Frieslaar, 2008)

This example explores the assessment of developing the N1 Corridor while exploring improvement options that include BRT, minibus taxi lanes, heavy and light rail and high occupancy vehicles and high occupancy toll lanes as well as additional freeway lanes, collector distributor lanes and bicycle lanes. The assessment as performed using both the SAW and EVAMIX method.

The alternatives explored were as follows:

1. Alternative 0: Do nothing,
2. Alternative 1: Upgrade Monte Vista rail service only,
3. Alternative 2: Lane balance to N1 Freeway only,
4. Alternative 3: Upgrade Monte Vista Rail and lane balance to N1 Freeway,
5. Alternative 4: Lane balance to N1 Freeway plus BMT lanes,
6. Alternative 5: Upgrade Monte Vista Rail, lane balance to N1 Freeway plus BMT lanes,
7. Alternative 6: Lane balance to N1 Freeway plus busway,
8. Alternative 7: Upgrade Monte Vista Rail, lane balance to N1 Freeway plus Busway,
9. Alternative 8: Upgrade Monte Vista Rail to Tram Train and lane balance to N1 Freeway, and
10. Alternative 9: Road pricing and lane balance to N1 Freeway plus bus service on Freeway.

The evaluation criteria included the following:

1. Spatial (land-use, accessibility, land-requirements),
2. Transportation (Public transportation use, travel speed, enforcement, freight transport, parking, private car use and reduction, reliability, frequency, etc),
3. Environmental (Fuel consumption, water bodies, non-motorised transport),
4. Social Environment (Safety and security), and
5. Costs (Capital costs and annual subsidies).

Weighting of criteria were decided by the City of Cape Town and Western Cape Government. Thereafter, both the SAW and EVAMIX methods were implemented. While the results between the methods differed, the two methods agreed that Alternative 6 would result in the most beneficial impacts (Vanderschuren & Frieslaar, 2008).

Appendix D: Example of Survey

Pairwise Comparison of Factors related to Public Transport

Good day,

Thank you for taking the time to answer this survey.

BACKGROUND

My name is Shameez Patel Papathanasiou and I'm in the process of investigating the use of multi-criteria decision-making methods in the evaluation of public transport planning.

As part of the research, I have selected criteria to use in the analysis and the criteria will be weighted using the analytical hierarchy process and nine-point scale as developed by Saaty (1980).

Please see the criteria chosen and defined below:

Cost	Capital cost and maintenance for operators/municipality
Land-Use and Integration	Value of land devoted to transportation facilities as well as integration with NMT (non-motorised transport)
Affordability for Users	Estimated cost of travel for the user
Accessibility	Geographical accessibility - size of serviceable areas
Speed	User travel time
Convenience and Reliability	Availability of facilities at stops and in-vehicle, toilets, seating, air-con etc. and expected and experienced arrival times
Environmental Effects	Fuel Consumption and carbon emissions
Safety	Safety and security of the user

Please note that should the data for a particular criterion be found to be inconsistent or insubstantial, the criterion will be left out of the investigation.

INSTRUCTIONS

The criteria weighting will be established by pairwise comparison – meaning – how important criteria A is relative to criteria B using the preference index shown below:

Rating	**How important is *A* relative to *B?***	**Explanation**
1	**Equally important**	**Two criteria contribute equally to the objective**
3	**Moderately more important**	**Experience and judgement slightly favour one criteria over the other**
5	**Strongly more important**	**Experience and judgement strongly favour one criteria over the other**
7	**Very strongly more important**	**A criteria is strongly favoured over the other (its dominance may even be demonstrated in practice)**
9	**Overwhelmingly more important**	**The evidence favouring one criteria over the other is the highest possible order of affirmation**

Therefore, in each question you will be required to decide the importance of one criteria over the other by adjusting the slider in the direction of the criteria preferred. See examples below.

Example 1 is shown below and the position of the marker indicates that *LAND-USE is MODERATELY more important than COST*

Example 2 is shown below and the position of the marker indicates that *COST is VERY STRONGLY more important than LAND-USE*

There are 32 questions in this survey and will take approximately 10 minutes to answer.

Thank you for your participation.

* 1. Do you consent to your ratings being used as described above? You must answer 'yes' to proceed with the survey. (Please note your names & personal information will not be used)

- [ ] Yes

* 2. Name & Surname (Please note this will not be used to contact you, only to keep track of inputs)

[ ]

* 3. Email Address (Please note this will not be used to contact you, only to keep track of inputs)

[ ]

* 4. Tick the option which best describes you

- ( ) WCG Employee within Transportation/Traffic
- ( ) CoCT Employee within Transportation/Traffic
- ( ) Academic within Transportation/Traffic
- ( ) Transportation/Traffic Engineer
- ( ) Planner/Project Manager/Other working with projects affected by Transportation/Traffic such as Sustainable Energy/Network Planning etc.
- ( ) General Public (Has used public transport)
- ( ) General Public (Has NOT used public transport)
- ( ) Other (please also specify if you're not in/from South Africa)

[ ]

5. How do you judge that COST compares with LAND-USE & INTEGRATION regarding public transport?

(Slide the centre in the direction of the criteria you deem more important, the closer you slide it to the criteria, the more important it is over the other criteria)

COST (9 - Overwhelmingly important)	1 - EQUALLY IMPORTANT	LAND-USE & INTEGRATION (9 - Overwhelmingly Important)

6. How do you judge that COST compares with AFFORDABILITY regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	AFFORDABILITY (9 - Overwhelmingly Important)

7. How do you judge that COST compares with ACCESSIBILITY regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	ACCESSIBILITY (9 - Overwhelmingly Important)

8. How do you judge that COST compares with SPEED regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	SPEED (9 - Overwhelmingly Important)

9. How do you judge that COST compares with CONVENIENCE & RELIABILITY regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	CONVENIENCE (9 - Overwhelmingly Important)

10. How do you judge that COST compares with ENVIRONMENTAL EFFECTS regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	ENIVRONMENT (9 - Overwhelmingly Important)

11. How do you judge that COST compares with SAFETY & SECURITY regarding public transport?

COST (9 - Overwhelmingly Important)	1 - EQUALLY IMPORTANT	SAFETY (9 - Overwhelmingly Important)

12. How do you judge that LAND-USE & INTEGRATION compares with AFFORDABILITY regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	AFFORDABILITY (9 - OVERWHELMINGLY Important)

13. How do you judge that LAND-USE & INTEGRATION compares with ACCESSIBILITY regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	ACCESSIBILITY (9 - OVERWHELMINGLY Important)

14. How do you judge that LAND-USE & INTEGRATION compares with SPEED regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	SPEED (9 - OVERWHELMINGLY Important)

15. How do you judge that LAND-USE & INTEGRATION compares with CONVENIENCE & RELIABILITY regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY Important)

16. How do you judge that LAND-USE & INTEGRATION compares with ENVIRONMENTAL EFFECTS regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY IMPORTANT)

17. How do you judge that LAND-USE & INTEGRATION compares with SAFETY & SECURITY regarding public transport?

LAND-USE & INTEGRATION (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY IMPORTANT)

18. How do you judge that AFFORDABILITY compares with ACCESSIBILITY regarding public transport?

AFFORDABILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	ACCESSIBILITY (9 - OVERWHELMINGLY IMPORTANT)

19. How do you judge that AFFORDABILITY compares with SPEED regarding public transport?

AFFORDABILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	SPEED (9 - OVERWHELMINGLY IMPORTANT)

20. How do you judge that AFFORDABILITY compares with CONVENIENCE & RELIABILITY regarding public transport?

AFFORDABILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY IMPORTANT)

21. How do you judge that AFFORDABILITY compares with ENVIRONMENTAL EFFECTS regarding public transport?

AFFORDABILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY IMPORTANT)

22. How do you judge that AFFORDABILITY compares with SAFETY & SECURITY regarding public transport?

AFFORDABILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY IMPORTANT)

23. How do you judge that ACCESSIBILITY compares with SPEED regarding public transport?

ACCESSIBILITY (9 - OVERWHELMINGLY IMPORTANT)	1 - EQUALLY IMPORTANT	SPEED (9 - OVERWHELMINGLY IMPORTANT)

24. How do you judge that ACCESSIBILITY compares with CONVENIENCE & RELIABILITY regarding public transport?

ACCESSIBILITY (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY Important)

25. How do you judge that ACCESSIBILITY compares with ENVIRONMENTAL EFFECTS regarding public transport?

ACCESSIBILITY (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY Important)

26. How do you judge that ACCESSIBILITY compares with SAFETY & SECURITY regarding public transport?

ACCESSIBILITY (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY Important)

27. How do you judge that SPEED compares with CONVENIENCE & RELIABILITY regarding public transport?

SPEED (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY Important)

28. How do you judge that SPEED compares with ENVIRONMENTAL EFFECTS regarding public transport?

SPEED (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY Important)

29. How do you judge that SPEED compares with SAFETY & SECURITY regarding public transport?

SPEED (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY Important)

30. How do you judge that CONVENIENCE & RELIABILITY compares with ENVIRONMENTAL EFFECTS regarding public transport?

CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY Important)

31. How do you judge that CONVENIENCE & RELIABILITY compares with SAFETY & SECURITY regarding public transport?

CONVENIENCE & RELIABILITY (9 - OVERWHELMINGLY Important)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY Important)

32. How do you judge that ENVIRONMENTAL EFFECTS compares with SAFETY & SECURITY regarding public transport?

ENVIRONMENTAL EFFECTS (9 - OVERWHELMINGLY important)	1 - EQUALLY IMPORTANT	SAFETY (9 - OVERWHELMINGLY important)