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Energetic, economic and socio-environmental assessment of alternatives for collective urban transport systems based on the multicriteria decision support model

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DECLARAÇÃO DO AUTOR

DECLARAÇÃO DA EDITORA

To my parents, Alcides and Anna Maria.

To my wife and children, Benedita, Felipe and Henrique.

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Rule I: Studies must aim to guide the spirit, so that we can formulate firm and true judgments about all things that come before it.

Rule II: It is convenient to deal exclusively with those objects of which our spirit is capable of reaching a certain and undoubted knowledge.

Rule III: Concerning the objects considered, we must investigate not what others have thought or what we ourselves suspect, but what we can have a clear and evident intuition, or what we can deduce with certainty, for otherwise science cannot be acquired.

Rule IV: Method is necessary for the search for truth.

Rule V: Every method consists in the order and arrangement of things, towards which it is necessary to direct the acuity of the spirit in order to discover the truth. We will observe this faithfully, if we gradually reduce complicated and obscure propositions to simpler ones, and if afterwards, starting from the intuition of the simplest, we try to raise ourselves by the same degrees to the knowledge of all the others.

Rule VI: In order to distinguish the simplest things from the most complicated, and to proceed in an orderly way in the investigation, it is convenient, in every series of things in which we directly deduce some truths from others, to observe which is the simplest and how all the others are more, less, or equally distant.

Rule VII: to complete science, we must examine with a continuous and never interrupted movement of thought each and every one of the things that relate to our purpose and bring them together in a sufficient and orderly enumeration.

Rule VIII: if in the series of things to be investigated there is something that our understanding cannot intuit sufficiently well, it is necessary to stop there, without examining the others that follow, thus avoiding superfluous work.

Rule IX: it is necessary to direct all the strength of the mind to the less important and easy things and to dwell on them long enough, until one gets used to seeing the truth by intuition in a clear and distinct way.

Rule X: In order for the mind to become sagacious, it must exercise itself in investigating the same things that have already been found by others and in going through with method all the artifices of men, and especially those that they manifest or suppose.

Discours de la Méthode de bien Conduire sa Raison et Chercher la Verité dans les Sciences
Extract from - Rules for Guiding the Spirit
René Descartes (1596 – 1650)

ABNT	(*Associação Brasileira de Normas Técnicas*) Brazilian Association of Technical Standards
LCA	Life Cycle Assessment
AEAMESP	Association of Engineers and Architects of the São Paulo Metro
AHP	Analytic Hierarchy Process
AMD	(*Apoio Multicritério à Decisão*) MDS - Multicriteria Decision Support
ANTP	(*Associação Nacional de Transportes Públicos*) National Association of Public Transport
BRT	Bus Rapid Transit
Btu	British thermal unit
CBTU	(*Companhia Brasileira de Trens Urbanos*) Brazilian Urban Train Company
CILCA	International Conference on Life Cycle Assessment
CNT	(*Confederação Nacional de Transportes*) National Transport Confederation
CREA	(*Conselho Regional de Engenharia e Arquitetura*) Regional Council of Engineering and Architecture
CS	(*Custo do Sistema*) System Cost Criterion
CSCE	(*Custo do Sistema*) Subcriterion Cost of Energy to operate vehicles
CSCR	(*Custo do Sistema*) Subcriterion Cost for System Renewal
CSII	(*Custo do Sistema*) Subcriterion Investment in rolling Infrastructure
CSIV	(*Custo do Sistema*) Subcriteria Investment in Vehicles
CSOMI	(*Custo do Sistema*) Subcriterion Cost of Operation and Maintenance of the rolling Infrastructure
CSOMV	(*Custo do Sistema*) Subcriteria Vehicle Operation and Maintenance Cost
CTB	(*Código de Transito Brasileiro*) Brazilian Traffic Code
DETRAN	(*Departamento de Transito*) Department of Transport
EE	Energy Efficiency
EnANPAD	Meeting of the National Association of Post Graduation Studies and Research on Administration
GEE	(*Gás de Efeito Estufa*)
GHG	Greenhouse Gas
GLT	Guided Light Transit

HCT	(Hospital Cidade Tiradentes) Cidade Tiradentes Hospital Station - Line 15 Monorail SP
IA	(*Impacto Ambiental*) Environmental Impact
IE	(*Intensidade Energética*) Energy Intensity
IAGEE	(Impacto *Ambiental) GEE - Subcriterion*) Subcriterion IA Greenhouse Gas
IADV	(*Impacto Ambiental*) Subcriterion IA Road System Division caused by rolling infrastructure
IARE	(*Impacto Ambiental*) Sub-criterion IA External noise to the vehicle
IASO	(*Impacto Ambiental*) Subcriterion IA - area occupied on the street-road by the rolling infrastructure
IATI	(*Impacto Ambiental*) Subcriterion IA - System Installation Time
IAVE	(*Impacto Ambiental*) Visual IA - Subcriterion Aesthetics of the road infrastructure
IER	(*Infra Estrutura de Rolamento*) Rolling Infrastructure
ISO	International Organization for Standardization
ITDP	Institute for Transportation & Development Policy
LCA	Life Cycle Assessment
LRT	Light Rail Transit
MCDA	Multicriteria Decision Analysis
MDS	Multicriteria Decision Support
MNT	Monorail (Abbreviation adopted in this work)
MR	(*Material Rodante*) Rolling Stock (Trains and Auxiliaries vehicles)
O&M	Operation and maintenance
ORT	(*Oratório Station*) Estação Oratório – Line 15 Monorail SP Metro
PRT	Personal Rapid Transit
QV	(*Qualidade da Viagem*) Trip Quality Criterion
QVAU	(*Qualidade da Viagem*) Subcriterion QV - Universal Accessibility
QVPV	(*Qualidade da Viagem*) Subcriterion QV - Trip Punctuality (means schedule on time)
QVRI	(*Qualidade da Viagem*) Subcriterion QV - Vehicle Internal noise

QVSIP	(*Qualidade da Viagem*) Subcriterion QV - Passenger Information System
QVSVS	(*Qualidade da Viagem*) Subcriterion QV - Safety between Vehicles of the System
QVSVV	(*Qualidade da Viagem*) Subcriterion QV - Safety between Vehicles in the System and Vehicles in the street
QVVM	(*Qualidade da Viagem*) Subcriterion QV - Average Speed
RMGSP	(*Região Metropolitana da Grande São Paulo*) Greater São Paulo Metropolitan Region
SIN	(*Sistema Interligado Nacional*) Electrical National Grid - Brazilian
SGA	(*Sistema de Gestão Ambiental*) Environmental management system
SMT	(*Estação São Mateus*) São Mateus Station - Line 15 Monorail São Paulo Metro
STUP	(*Sistema de Transporte Urbano de Passageiros*) Urban Passenger Transport System
TC	(*Transporte Coletivo*) Collective Transportation System for passengers
TD	(*Tomador de Decisão*) Decision Maker
TI	(*Transporte Individual*) Individual Transport (by car)
TIR	(*Taxa Interna de Retorno*) Internal Rate of Return
TPU	(Transporte Público Urbano) Urban Public Transport
TRI	(*Tempo de Retorno do Investimento*) Payback Time
TUC	(*Transporte Urbano Coletivo*) Collective Urban Transport
UITP	(*União Internacional de Transporte Público*) International Union of Public Transport
UT	(*Unidade de Transporte*) Transport Unit
VCA	(*Voltagem de Corrente Alternada*) Voltage with Alternating Current
VEF	(*Viabilidade Econômica e Financeira*) Economic and Financial Feasibility
VEFTIR	(*Viabilidade Econômica e Financeira*) Subcriteria TIR - Internal Rate of Return
VEFTRI	(*Viabilidade Econômica e Financeira*) Subcriteria TRI - Payback Time

VEFVPL	(*Viabilidade Econômica e Financeira*) Subcriteria VPL - Net Present Value
VLP	(*Veículo Leve sobre Pneus*) Light Vehicle on Tires (BRT)
VLT	(*Veículo Leve sobre Trilhos*) Light Rail Tram (LRT)
VPA	(*Vetor Prioridade de Alternativa*) Alternative Priority Vector
VPC	(*Vetor Prioridade de Critério*) Criterion Priority Vector
VPL	(*Valor Presente Líquido*)Net Present Value
VPM	(Estação Via Prudente)Vila Prudente Station - Line 15 Monorail - SP Metro
VPSC	(*Vetor Prioridade de Subcritério*) Subcriteria Priority Vector

C	Decision Agent: Consultant / Researcher in Collective Urban Transport
CO_2	Carbon Dioxide (Carbon Anhydride)
CV	Horse Steam (*Cavalo Vapor*)
Db	Decibel
F	Decision Agent: Equipment / Service Provider or Supplier (*Fornecedor*)
j	Joule
Km	Kilometer
mi	Million
min	Minute
Mj	mega joule
O	Decision Agent: Operator (Operator or Authority of a given transportation System)
p	Passenger
p/h/s	Passenger per hour per direction
p-km	Passenger per kilometer
s	Second
t	Time
T	Tera = 10^{12}
U	Decision Agent: User (User of a given transportation system)
V	Decision Agent: Neighbor (Neighbor of a given transportation system)

PEDROSO, Guilherme. Energetic, economic and socio-environmental assessment of alternatives for collective urban transport systems based on the multicriteria decision support model, 2017. 314 f. Thesis (Doctorate in Science) - Postgraduate Program in Energy - Institute of Energy and Environment of the University of São Paulo, São Paulo, 2017.

This research focuses on decision making for the choice of collective urban transport modes and analyzes the operational and functional performance of the Bus Rapid Transit (BRT), Light Rail Vehicle (VLT) and Monorail systems. A multicriteria decision support (MDA) model in complex scenarios is used in the analysis and has as input data the subjective preferences of decision agents (stakeholders) and the objective and subjective performances of the three modes in relation to a system of five criteria and 22 sub-criteria. Such a system covers the axes of energy efficiency, cost, economic and financial viability, trip quality and environmental impacts. Stakeholders selected with operator, neighbor, user, equipment and service supplier and consultant profiles assign their preferences, scoring them on a numerical scale from 1 to 9. Aiming at the application of the model in the region of São Paulo, 138 opinions were collected from preferences through evaluation forms and interviews conducted in this region. Each of the three modes, after being configured to meet the operational and functional requirements of the transport service defined by a common functional unit, has its performance against the same set of criteria and sub-criteria scored on a numerical scale. A global index (GI), which defines the priority of each alternative, is obtained by aggregating preferences and performances with an additive function. The model was applied in a case study that simulated the operation of the three modes in the stretch between Vila Prudente and São Mateus stations on Line 15 of the São Paulo Metro, whose requirements defined the functional unit. Within the limits and premises established for this case study, the global indices calculated indicated a preference for the Monorail modal, followed, in order, by the VLT and BRT.

KEYWORDS: Collective Urban Transport. BRT, VLT and Monorail modes. Multicriteria Decision Support. Criteria - energy efficiency and socio-environmental aspects.

PEDROSO, Guilherme. ***Avaliação energética, econômica e socioambiental de alternativas para sistemas de transportes urbanos coletivos a partir do modelo de apoio multicritério à decisão.*** *2017. 314 f. Tese (Doutorado em Ciências) – Programa de Pós-Graduação em Energia – Instituto de Energia e Ambiente da Universidade de São Paulo, São Paulo, 2017.*

Essa pesquisa tem como foco a tomada de decisão para a escolha de modais de transporte urbano coletivo e analisa os desempenhos operacionais e funcionais dos sistemas Bus Rapid Transit (BRT), Veículo Leve sobre Trilhos (VLT) e Monotrilho. Um modelo de apoio multicritério à decisão (AMD) em cenários complexos é utilizado na análise e tem como dados de entrada as preferências subjetivas de agentes de decisão (stakeholders) e os desempenhos objetivos e subjetivos dos três modais com relação a um sistema de cinco critérios e 22 subcritérios. Tal sistema cobre os eixos de eficiência energética, custo, viabilidade econômica e financeira, qualidade da viagem e impactos ambientais. Stakeholders selecionados com perfis de operador, vizinho, usuário, fornecedor de equipamentos e serviços e consultor atribuem suas preferências, pontuando-as em escala numérica de 1 a 9. Visando a aplicação do modelo na região da cidade de São Paulo, foram coletadas 138 opiniões de preferências através de formulários de avaliação e entrevistas conduzidas nessa região. Cada um dos três modais, após ser configurado para atender aos requisitos operacionais e funcionais do serviço de transporte definido por uma unidade funcional comum, tem os seus desempenhos com relação ao mesmo conjunto de critérios e subcritérios pontuados em uma escala numérica. Um índice global (IG), que define a prioridade de cada alternativa, é obtido pela agregação das preferências e desempenhos com uma função aditiva. O modelo foi aplicado em um estudo de caso que simulou a operação dos três modais no trecho entre as estações Vila Prudente e São Mateus da Linha 15 do Metrô de São Paulo, cujos requisitos definiram a unidade funcional. Dentro dos limites e premissas estabelecidas para este estudo de caso, os índices globais calculados indicaram a preferência pelo modal Monotrilho, seguido, na ordem, pelo VLT e BRT.

PALAVRAS-CHAVE: Transporte Urbano Coletivo. Modais BRT, VLT e Monotrilho. Apoio Multicritério à Decisão. Critérios – eficiência energética e aspectos socioambientais.

SUMMARY

SUMMARY

INTRODUCTION

THEME AND SCENARIO

The migration of people to urban areas in recent years has increased the dispersion and movement of these people in cities, which has resulted in the consequent demand for public and individual motorized transport.

The current urban transport model, which favors the individual transport, added to the low level of investments in good quality public transport, has saturated urban roads in large cities to the point of jeopardizing the traffic flow, especially at daily peak period of times. These facts cause negative externalities in mobility by promoting transit congestion and high travel time with consequent people discomfort, energy waste and environmental impacts. To minimize the impacts caused by these growing changes in the almost daily scenario of large urban centers, the authorities responsible for the means of transport need to address urban mobility with public policies aimed at encouraging and modernizing collective urban transport, targeting to improve travel as comfort, reliability, security, universal accessibility and connectivity between the different modalities. In addition, they should also promote and direct incentives for the production of low-emission engines, free of atmospheric pollutants. Endowed with these characteristics, collective urban transport can attract users of private vehicles, what has direct effects on freeing up space on urban roads, improving traffic flow and reducing other negative externalities of urban traffic (BOARETO, 2008; MINISTÉRIO DAS CIDADES, 2008).

In Brazil, the daily per capita travel indicator published by the Urban Mobility Information System of the National Public Transport Association (ANTP) records that, between 2003 and 2012, in Municipalities with 60 thousand inhabitants or more (438 municipalities), individual transport modes (car and motorcycle) increased by 18%, while collective transport (buses and rail vehicles) increased by 6%. In the same period, other indicators point out that, while the population increased by 16%, the number of cars increased by 70% and motorcycles by 29% (ANTP, 2014).

The mobility of people along urban roads is carried out through different modes of transport that complement each other forming an integrated network.

Among the available modes for individual and collective transport are: bicycles, motorcycles, cars, vans, buses, suburban trains, subways, light rail vehicles (tramways), the so-called Personal Rapid Transit (PRT), Guided Light Transit (GLT), Bus Rapid Transit (BRT), Light Rail Transit (LRT) and Monorail (BRASIL, 2012; MINISTRY OF CITIES, 2008; SENADO, 2013; VUCHIC, 2007).

Considering the context described above, this research analyzes the performance of some attractive alternatives of vehicles dedicated to the collective urban mobility in the urban region. The focus is on people traveling on urban rapid transit corridors and a case study compares the functional and operational performances of the BRT, VLT and Monorail (MNT) modes, operating on this type of scenario.

The question that is proposed to be answered in this work, using the MDS technique (Multicriteria Decision Support), cares about the efficiency of the modals. More specifically, among the BRT, LRT and MNT modes, which one would to be the most efficient one to equip public (collective) transport corridors of medium transportation capacity?

The case study compares the performances of the three systems with a model that processes the preferences of stakeholders (interested parts, also referred as decision agents in this work) and the performance of each of the three modals in relation to a set of multiple criteria and sub-criteria indexes.

Five criteria and 22 sub-criteria were defined to cover the aspects of cost, economic and financial feasibility, energy efficiency, quality of travel and environmental impacts.

The stakeholder assigns preferences (levels of importance) to each criterion and sub-criterion, scoring them on a numerical scale. An investigation is conducted to collect preferences for public urban transport from stakeholders leaving in the city of São Paulo.

The three alternatives under analysis are configured to meet the functional and operational requirements of a common operational scenario defined by a functional unit (ISO NBR 14040/14044). After configuration, the performances of each modal against the same set of criteria and sub-criteria are also scored with a numerical scale.

A global index of importance for each alternative is calculated, making the correlation between preferences and performances, with an additive function according to the Analytic Hierarchy Process (AHP) method.

This method was chosen because it is widely used to support decision-making in problems inserted in the context of complex scenarios, such as the one discussed here, in which multiple criteria, multiple stakeholders and more than one possible alternative solution are present (GOMES, 2004; MACHARIS, 2015; SAATY, 1991; SAATY, 2008; SOLTANI, 2015).

Although the Monorail is the modal that already operates in the transit corridor that is the object of the case study, the work investigates, with the proposed decision-making support model and the established premises, whether this would have been the preferred solution when compared to the BRT and VLT technologies.

JUSTIFICATION

Relevance

The carrying out of this research is justified due to the important themes with which it dialogues, as well as: the socio-environmental relevance of collective urban transport; sustainable urban mobility; the search for modes of collective urban transport with sufficient quality to attract users of individual transport; and methods to support decision-making by agents responsible for planning and implementing efficient urban infrastructure. Faced with these themes, the work carried out, in a practical case study, the evaluation of the performance of three specific modes for collective urban transport of medium transport capacity, currently considered as attractive for users of individual transport.

Originality

Considering the question of the originality of the research, seven elements stand out:

- Adoption of a specific set of Criteria (5) and Sub-Criteria (22). Such a set constitutes the reference for the evaluation of the preferences of decision agents (stakeholders) and the performances of the modes;
- Use of the concept of Functional Unit (item 4.1 p. 74) to define the basis of functional and operational requirements to which the modals being compared must equally meet in order to homogenize the applications.

When analyzed individually, from the consulted bibliography, it is possible to infer that the BRT is a system that was originally designed to operate in segregated corridors built at the street level.

In turn, the tramway was designed to operate on hybrid corridors, with partially segregated sections and/or shared traffic with other vehicles, but it can also operate on a segregated lane. Finally, the Monorail was designed for operations in segregated corridors, with a preferentially elevated track in relation to the street level traffic. The Functional Unit then serves as a reference for the structural equalizations of the three systems so that they can then be compared. To enable the comparison of these three modes, the Functional Unit could equalize the operation of these systems in: segregated lane at street level, segregated lane above the street and, or, semi-segregated at the street level. In this work, the Functional Unit of the case study opens the way for two possible solutions to be adopted: one, with total segregated elevated infrastructure for the three modes; another one, considering the elevated solution for the MNT, already under operation in the target corridor, and the other two modes, BRT and LRT, running at the street level in segregated lanes from the normal traffic with transit priority provided by controllable traffic lights.

- Adoption of five classes of Decision Agents: Operator, Neighbor, User, Supplier and Consultant;
- Preparation and application of Annex I (Procedure - Preference of Decision Agents by the criteria and sub-criteria) and processing and registration of Preferences in Annex II (Tables - Preferences of Decision Agents) that documents the search for preferences;
- Preparation of Annex III, which documents the calculations for obtaining the Performance of Alternatives;
- Preparation of preference priority vectors (VPC and VPSC) and alternative priority vectors (VPA) for the case study. These vectors are constructed with the data presented in annexes II and III;
- Calculation of Global Indices that characterize the priorities of each Alternative (IG) for the case study.

Personal Interest

The interest in carrying out this study occurred after the development of a Master's thesis (PEDROSO, 2012) and publication of articles (PEDROSO, 2013a and 2013b) in which studies were carried out on sustainability indicators in transport and comparisons between the BRT and VLT modes on the environmental, economic and social fields. This work has a wider scope, as it introduces the Monorail performance analysis and the feasibility criteria for economic and financial, energy efficiency and travel quality. In addition to these novelties, the research developed an analysis model that used the AHP method as a guide.

HYPOTHESES

First question - Would it be possible to compare the functional and operational performance of modes for collective urban transport that are originally designed to be used in apparently specific application niches?

In response to this question, the hypothesis is that: modals can be directly compared as long as the study is carried out on a basis of common requirements, defined by a Functional Unit.

Second question - Would it be possible to develop a model capable of combining the subjective preferences of decision-makers for criteria and sub-criteria with the objective and subjective functional and operational performances of transport modes and process such information with the objective of ordering the modes in order of priority?

In response to this question, the hypothesis is that: the preferences of decision makers can be captured and quantified with specific procedures and interviews; the performances of the alternatives are present in the bibliography and can be complemented with observations on installed systems; and the AHP method can be used to solve the problem of aggregating the set of preferences and performances with an additive function and establishing the ordering of the modals in order of priority.

Still a third and final question, which gave rise to the definition of the scenario of the Functional Unit of the case study - Would the Monorail have been the best option to equip Line 15 - Silver of the São Paulo Metro, when confronted with the performances of the BRT and LRT modals?

In response to this question, the hypothesis is that a decision support model for complex scenarios in which multiple criteria, multiple decision agents and several viable alternatives are present can objectively ratify or rectify the decision taken towards the selected modal.

GOALS

The research objectives are classified into general and specific.

General Objectives

The general objective of the research is to compare the functional and operational performances of the BRT, VLT and Monorail modes and prioritize them according to the preferences of stakeholders and to their individual performances when delivering people transportation services in a common scenario defined by a Functional Unit and multiple criteria and sub-criteria.

Specific Objectives

To achieve the general objective, the following specific objectives were defined and followed:

- Definition of the model for carrying out the modes comparison;
- Definition of multiple criteria and sub-criteria;
- Definition of stakeholders;
- Survey of preferences of stakeholders (Annexes I and II);
- Application of the model to a practical case study:
    - Definition of the Functional Unit;
    - Definition of alternatives (modals);
    - Configuration of each alternative to meet the requirements of the Functional Unit;

- Survey of the performance of each alternative (Annex III);
- Calculation of the Global Index (GI) of each alternative;
- Ordering the alternatives in order of priority, according to their GIs.

CASE STUDY ASSUMPTIONS

Below are the assumptions adopted for the elaboration of the case study.

- The geographic scenario and the functional and operational requirements common to the three modes under comparison are defined by the Functional Unit;
- Criteria and sub-criteria limited to the selected set;
- The preferences of stakeholders by the criteria and sub-criteria are restricted to the opinion poll documented in Annexes I (procedure) and II (collected data);
- The functional and operational performances of the three modes under comparison are as recorded in the calculation memorial described in the Annex III;
- As the objective of the decision problem is to compare the performances of the three modes, there are elements considered common among them and, within an acceptable margin of error, they are excluded from the analysis: costs of auxiliary systems (escalators, elevators, ventilation, lighting, ticketing and other station and trackside equipment), Operational Control Center, telecommunications system and also parking and vehicle maintenance yards;
- The update of civil construction costs made by the National (Brazilian) Index of Civil Construction issue periodically by the (Getúlio Vargas Foundation) Fundação Getúlio Vargas (FGV, 2017);
- US dollar conversion rate based on the table issued periodically by the Central Bank of Brazil;
- Average cost of BRL 2.936 for 1.0 liter of Diesel oil (ANP, 2017) and the average cost of BRL 0.324 for 1.0 kWh of electricity (AES, 2017);
- The metric of 1/IE (1/Energy Intensity) per passenger transported per day to characterize the Energy Efficiency criterion;
- The use of an average emission factor of 2.67 kgCO_2eq per liter of diesel fuel burned in the combustion of the BRT vehicle's internal combustion engine and 0.5 kgCO_2eq to produce and distribute one liter of diesel oil (CARVALHO, 2011; EMBRAPA, 2009);
- Adoption of the average emission factor of 81.7 kgCO_2eq per MWh consumed from the National Interconnected System (SIN) network, published by the Ministry of Science and Technology (MCT, 2017) for 2016.

CONTRIBUTIONS OUT OF THE STUDY

The first contribution of the research was the production of a database with information on the level of importance that decision-makers (stakeholders - herein defined as: operator, user, neighbor, equipment and service provider and consultants and researchers) involved with collective urban transport systems assigned to the criteria and sub-criteria adopted in this work.

A second contribution of the study was the production of another set of data regarding the performance of the BRT, VLT and MNT modes in relation to the same criteria and sub-criteria. It is understood that these data will be useful for agents involved with public urban transport systems that mainly develop planning and management activities in this field.

A third contribution is the detailed descriptions of the step-by-step applications of the proposed model and the AHP method.

From an academic point of view, the work developed two different materials: a system of criteria and sub-criteria for evaluating modes in collective urban transport, with a sustainability bias; and a practical case study which applied such system to evaluate three specific people transportation modes. It is also noteworthy that the research applied fundamentals from the areas of Collective Urban Transport, Life Cycle Assessment (LCA) and Decision Making in Complex Scenarios.

STRUCTURE

The work is structured in 6 chapters, including in this count this Introduction and a brief Conclusion.

Chapter 2, **Theoretical Reference**, presents the bibliographic base that underlies the development of the research. The topics studied cover: transport, energy, energy efficiency, collective urban transport, characterization of BRT, VLT and MNT modes, support for decision-making in complex scenarios with emphasis on the AHP method, examples of application of the AHP method in collective urban transport and brief description of the concept of Functional Unit.

Chapter 3, **Method**, deals with the nature of the research, the macrostructure of the decision support model of this work and the steps for carrying out the case study.

Chapter 4, **Results**, shows the preferences of decision-makers, the performance of the three modes of the case study, their classification in order of priority and the analysis of the results.

And, in Chapter 5, **Global Discussion**, the results obtained are evaluated against the general and specific objectives and against the stipulated hypotheses. The boundaries of the research are also described in it, along with the description of the main lessons learned and offering suggestions on further research, ending with a brief **Conclusion** of work.

ANNEXES

There are 6 **Annexes** contained at the end of this reserarch.

- **Annex I** shows the procedure that was distributed to the agents (Stakeholders) invited to report their preferences in relation to criteria and sub-criteria set;
- The **Annex II** presents the tables with the data collected from the procedure shown in Annex I;
- **Annex III** constitutes the memorial for calculating the performance of the BRT, VLT and MNT modes, produced based on the information obtained through theoretical research and field observations;
- **Annex IV** presents an extract from The BRT Standard 2014 document, which shows the criteria and scores that define and qualify a BRT type bus transport system;
- **Annex V** shows a case study that exercises the decision support model (Figure 19) in the comparison between the performance of the GLT (Guided Light Transit) and LRT (Light Rail Transit) modes in a hypothetical application in the city of São Paulo.
- Finally, the **Annex VI** shows part of the Excel environment in which the Criteria, Subcriteria, VPC vectors (Priority Vector of Criteria), VPSC (Vector Priority of Subcriteria) and VPA (Priority Vector of Alternatives) and also the equations through which the Global Indices are calculated for the BRT, VLT and MNT alternatives.

THEORETICAL REFERENCE

Chart 1 summarizes the bibliographic survey carried out in works related to the themes, which served as a basis for the development of this work. Figure 1 shows the logical structure of the theoretical framework and its connection with the case study and the research results.

Summary of the Fundamental Bibliography		
Theme		Author
1	Energy Efficiency	De la RUE du CAN, 2010; ISO 50001:2011; BAEDEKER and HÜGING, 2012; BANAR 2013; METRÔ, 2014b ; KATO, 2006; KLIUCININKAS 2012; KUMAR, 2014 ;PATTERSON, 1996; SCHILLER 2010; VUCCHIC, 2007.
2	Transport and Transport Urban Collective	ALOUCHE, 2012; ANTP, 2014; BOARETO, 2008; BRAZIL, 2012; FARJERSTAJIN, 2012; RODRIGUES, 2008;MAGALHAES, 2010; McLEOD, 2007; MICHAELIS, 1996;MINISTRY OF CITIES, 2008; RODRIGUES, 2008; VUCCHIC, 2007.
3	BRT	ABNT NBR 9079; ALOUCHE, 2012; AGRO ANALYSIS, 2009; BRTBRASIL, 2014; BRT Sunway, 2015; BRT Xianen, 2008; CARVALHO, 2011; CINQUINA, 2008; GRANVILLE, 2014; LASCALA, 2011; Mercedez-Benz website; Scannia website; Novabus website; ISO 2001:2011; ITDP, 2014; ITDP, 2016; LERNER, 2009; MADISON, 2013; MINISTRY OF CITIES,2008; PATERSON, 1996; SPTRANS, 2013; VUCHIC, 2007
4	LRT	ABNT NBR, 1994; ALOUCHE, 2006; ALOUCHE, 2012; ALSTOM, 2017; BOORSE, 2000; EMTU (A), (B), 2013; Rio I Gowebsite; Viatrolebus website; LERNER, 2009; MCT, 2017;MINISTRY OF CITIES, 2008; PLANUS, 2015; CITY HALL-RIOSECPAR, 2016; RAILWAY-TECHNOLOGY, 2017; REVOLVY, 2017; REVISTA FERROVIÁRIA, 2015; SYSTRA, 2017; VOSSLOH, 2016; VTA, 2007; VUCHIC, 2007
5	MNT	ABNT NBR 1308; ALOUCHE, 2012; BOMBARDIER TRANSPORTATION, 2017; CICHINELLI, 2013; MECA, 2011;MECA 2013; METRO DE SP (2014b, 2015, 2016); JAPANMONORAIL ASSOCIATION, 2016; MONORAILS AUSTRALIA (a) (b), 2017; PLANUS, 2015; SCOMIRAIL, 2017; SEKITANI et al, 2005; MCT, 2017; MITSUBICHI HEAVY INDUSTRIES, 2017; REVISTA FERROVIÁRIA, 2015; ROCHA, 2016; STRUKTONRAIL, 2017; SKYTRAINCORP, 2017; THE MONORAIL SOCIETY, 2017; WIKIPEDIA.ORG, 2017
6	Support for Decision Making in Complex Scenarios; Methods - Support Multicriteria Decision	BALALI, 2014; BARAN, 2014; GOMES et al, 2004; MACHARIS et al, 2009; MACHARIS, 2015; SOLTANI, 2015; TERRADOS, 2010; VELASQUES, 2013; YU, 2011
7	AHP Method	BARAN, 2014; CARREIRA et al, 2014; GOMES et al, 2004; LUCA, 2014; MACHARIS, 2015; MU, 2017; SAATY, 1991; SAATY, 2008; SAATY, 2011; YU GOMES et al, 2004, 2011
8	Application of the Method AHP in Urban Transport systems	BANAI, R., 2006; BOUJELBENE, Y., 2015; LONGO, G., 2015; MACHARIS et al, 2009; MANOEL, MV, 2014; MORADIN, M., 2004; OLIVEIRA, GT, 2016

9	Criteria; Stakeholders; Indicators in Urban Transport syst4ms	BAEDEKER, 2012; BRYSON, 2011; DELL'OLIO et al., 2011; DE LA RUE DU CAN, 2010; FREEMAN, 1984; FREEMAN, 2017; GOMES et al., 2004; GOMES, 2014; HOLLINGWORTH, 2010; ITDP, 2016; KUMAR, 2014; LUPO,2013; MANOEL, 2014; MUNIER, 2011; MORAIS, 2011;PEDROSO et al., 2013B; RODRIGUES, 2008; SCHILLER et al, 2010
10	Functional Unit; Life Cycle Assessment (LCA)	BUO, 2015; CARVALHO, 2011; CHEHEBE, 2002; CHESTER, 2010; DAVE, 2010; EMBRAPA, 2009; CADES, Feb 2, 2011;CADES, February 24, 2011; EPAMINONDAS, 2011; MANZZINI and VELOZZI, 2008; MECA, 2011; MECA, 2013;METRO, 2017; PEDROSO et al, 2013a

Chart 1 - Summary of the fundamental bibliography.
Source: Prepared by the author.

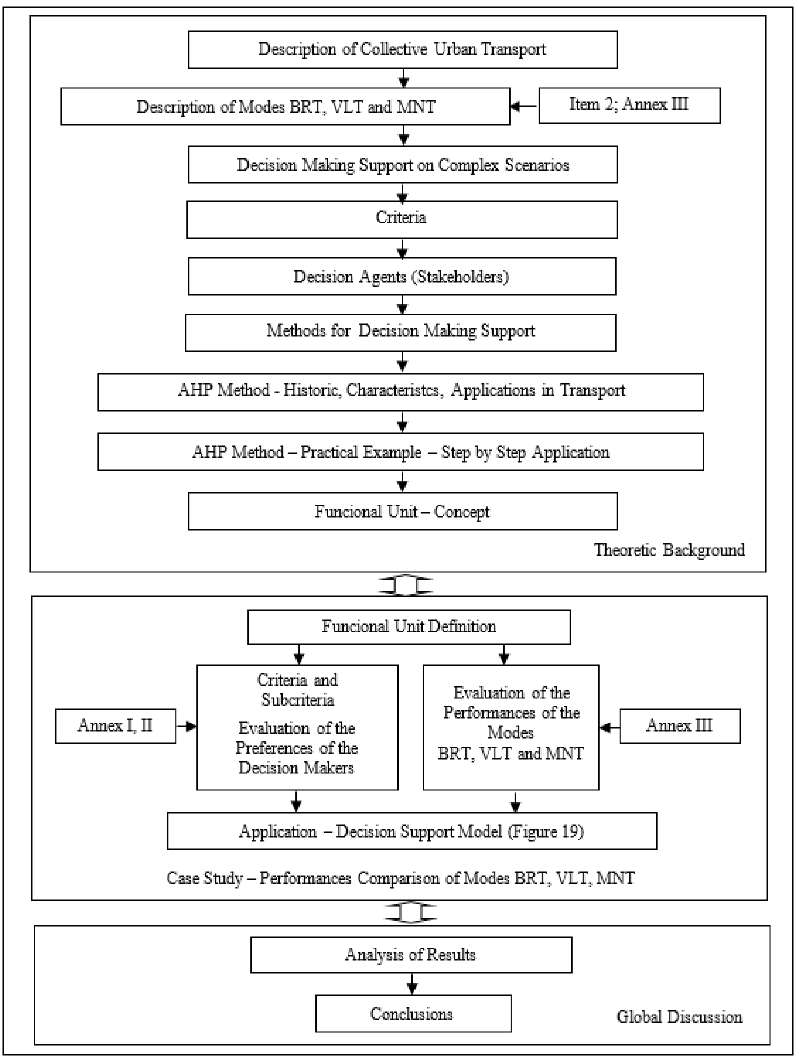

Figure 1 - Logical structure of the bibliographic study and connection with the case study
Source: Prepared by the author.

TRANSPORT, ENERGY AND ENERGY EFFICIENCY

Magalhães (2010) defines transport as a system, distinguishing between inputs and outputs. The entries constitute the people or items to be transported. Other inputs to this system are also: energy, artifacts (equipment in general) and economic, political, cultural and family actions. Useful outputs are people and other transported items, and also residues produced by of the activities carried out for the transportation of people and loads.

The needs of people to move throughout the urban space of cities as well as the objects to be transported and the own scenario of the study of this work, at the end, are all targeting to the development of activities like access to work, health, school, leisure, shopping and search for other services (MAGALHÃES, 2010; RODRIGUES, 2008; McLEOD, 2007; MICHAELIS, 1996).

In addition to people, another important input, also the object of attention of this research is the efficient consumption of energy by the urban transport systems.

Energy Intensity (IE) or energy consumption of a system are generic terms that define the relationship between the consumed energy (system input) needed to realize a productive unit (useful output). This relationship is also named as a consumption rate. The inverse relationship of the consumption rate defines the Energy Efficiency (EE) rate. An increase in consumption required to produce the same useful output reduces the energy efficiency of the system and vice versa (De la RUE du CAN, 2010; ISO 50001:2011; PATTERSON, 1996; VUCHIC, 2007).

Energy consumption, as a generic term, can, however, be interpreted in different ways. For example, a motorsport technician might consider a vehicle to be efficient when it requires less energy than another to travel the same distance at the same speed. In another example, an environmental technician's view might consider a vehicle to be efficient when it operates in a pool system with a high load factor (high load of people per vehicle). In order for energy efficiency to be included in the decision-making process at different organizational levels, it needs to be measurable and manageable. The measurement of input energies and the products and services that are produced in a system is done through indicators associated with parameters and metrics. Examples of applications of energy efficiency indicators are: indicators for monitoring energy consumption reduction targets in products manufactured; indicators for the dissemination of more efficient systems and equipment; indicators for the dissemination of less polluting systems and equipment; indicators for monitoring the use of incentives for technological development of less energy-intensive systems and equipment and indicators for labeling more efficient manufactured products (De la RUE du CAN, 2010).

Kumar (2014) developed an extensive work dedicated to the study of sustainability indicators in urban transport. Among these indicators there are those specifically cited as related to energy efficiency in public transport. All of them are presented as related to the environment. In its logic, a transport system which has an energy efficient fleet of vehicles brings the benefit of reducing pollutant gas emissions out of its energy consumption. This benefit, according to the author, could attract users of individual transport, especially those who use private cars, thus creating an even greater capacity to reduce gas emissions, in addition to improving environmental health. It defines that energy efficiency in public transport can be measured according to the distance traveled by a vehicle through the unit of volume of fuel consumed, which is usually expressed in km/l (kilometer traveled with one liter of fuel). Another indicator cited measures the percentage of the fleet that uses ecological fuel. And, a third one, measures the age of the vehicle fleet (older are less efficient, therefore more polluting). Finally, Kumar mentions an indicator that concerns to the number of vehicles that meet environmental pollution standards. By classifying these indicators, they can be understood as related to: vehicles (energy efficiency indicator; fleet age indicator, which is also related to the vehicular efficiency indicator; emission reduction indicator, which also has to do with vehicle efficiency); trips (percentage indicator between individual and collective transport; as described, there is a possibility for a modern fleet to attract individual transport users) and fuel (percentage indicator of non-polluting fuel utilization). From the author's perspective, one can better understand how the indicators fit into the concept of energy efficiency.

In the study carried out by Banar (2013), to identify the levels of atmospheric emissions associated with the consumption and quality of fuels in urban transport, the author distributed the focus of attention on three subsystems: infrastructure, vehicles and energy.

On the other hand, Kato (2006), also analyzing atmospheric emissions associated with energy consumption in urban transport systems, turned his focus to two subsystems components of the system: infrastructure, composed of two parts that are the road and other component elements such as stations, bridges, tunnels; and parking lots for rolling stock (passenger vehicles) and general maintenance rolling stock (trucks and cards).

Kliucininkas (2012) made a comparative analysis of public transport alternatives for the city of Kaunas, located in Lithuania. The modes of transport were medium-sized buses, consuming diesel oil, and trolleybuses, using electric energy. The analysis focused on the fuel chain used in the two systems and diesel oil. The performance of diesel oil was analyzed taking into account the stages of oil mining, transport to the production plant, refining and transport of diesel to the place of consumption by vehicles. The electricity generation chain also considered the generation stages, using oil, gas and transmission of electricity to the place of consumption. In all these stages, physical-thermodynamic indicators were used.

Vuchic (2007) breaks down the analysis of energy consumption in urban passenger transport systems into general categories of vehicle characteristics, rolling infrastructure and operational aspects. With regard to vehicles, he considers relevant the evaluation of: type of propulsion control; way it is guided on the track (with or without guide rail), specific weight in kg/m^2; ratio of seated passengers and standing passengers; auxiliary systems available (air conditioning and others); capacity and occupancy rate and the dynamic performances in relation to acceleration, braking and maximum speed rates. In road infrastructure, attention must be paid to the characteristics of curves and ramps and the type of wheel/rolling contact (steel wheel/rail; rubber tire/concrete). And as for the operational aspects, he considers them important in optimizing energy consumption and complying with the circulation program (time schedule), paying attention to points of turn-back, time distance between vehicles, use of express service (end to end trip) and all stations stopping vehicles and uniformity in the acceleration, deceleration and coasting (movement without forced application of acceleration or braking).

Also analyzing the issue of energy efficiency in passenger transport, Schiller (2010) questions whether this issue is restricted to fuels, vehicles or the traffic model of cities. According to him, from a fuel point of view, energy efficiency depends on vehicle technology and on the efficiency of the entire life cycle of fuel production, from its industrialization process up to the distribution at the consuming points. In addition to the technological evolution of vehicles and fuels, he mentions that these actions must be complemented with others, aiming at reducing the number of cars – an index that continues to increase in large cities. Outside the northern European countries, the author considers insufficient, or even non-existent, actions in terms of the application of policies and planning mechanisms aimed at mobility models, which encourage the reduction of car use and non-motorized displacement in cities.

Baedeker and Hüging (2012) ratify Schiller's (2010) approach and argue that energy efficiency in transport should be analyzed in terms of vehicle performance, the modes that are used to travel and the performance of the system as a whole. At each of these levels, energy efficiency can be increased through different treatments. Vehicles can become more efficient thanks to technologies that develop new fuels, reduce engine consumption, reduce weight, reduce frictional losses and improve aerodynamics, to name a few variables that must be considered. As for modes, trips made with public and non-motorized transport are more energy efficient than individual modes. And for the system as a whole, attention should be given to a reduction of trips by organizing the land use and interactions among economic and social activities with transportation systems.

In urban passenger transport, energy consumption is usually measured by the ratio between the energy consumed and the number of passengers (p) transported between points of origin and destinations. Ratio metrics can be, for example, kWh/p-km, or joules-p-km and, or, liters of fuel per passenger carried per km (l/p-km). Precise figures on energy efficiency are difficult to estimate due to the number of factors that affect the calculations. These factors are, for example: the scope of the assessment (Whole system? Only Vehicles? Vehicles plus road infrastructure? etc); types of energy; vehicle characteristics; characteristics of the roadway (technology and layout); operational aspects (expressways, locations and operating regimes); energy consumed by vehicles outside the normal operating scenario (for example, when they are in maintenance workshops); knowledge of the energy consumed per vehicle/km for different loads and influences due to factors external to the direct operation of people transport vehicles (e.g. energy consumed in the system by maintenance teams with special vehicles) (VUCHIC, 2007).

As an example of the application of this type of metric, we cite data of the São Paulo Metro, which transported an average of 1,110,432,599 passengers on working days in 2014, its trains traveled the equivalent of 18,065,234 km and were consumed in the year in the order of 540,000 MWh in the operation of transport services (METRÔ, 2014b). Based on these data, the distribution of consumption per passenger in that year was 0.486 kWh/passenger and consumption per km was 29.9 kWh/km.

In general, the authors cited understand that comprehensive analyzes of consumption and, consequently, energy efficiency, in transport systems in general or in collective urban transport, should consider vehicles, infrastructure of stations and roads and operational strategies. Individual analyzes of these subsystems can be conducted with the proper delimitations of well-identified boundaries.

COLLECTIVE URBAN TRANSPORT

According to the International Union of Urban Transport (UITP), the process of urban mobility is a major challenge that cities face to overcome difficulties with transport systems, given the increase in the world population that is increasingly urbanized. Currently, 53% of the population resides in urban areas and, by 2050, this number is expected to reach 67%. Today, 64% of trips are made within the urban environment and the total number of kilometers traveled is expected to increase three times by 2050. To meet this growth forecast, collective urban transport will have to increase its share in relation to private transport and, therefore, large investments will need to be allocated to urban mobility. Then UITP has the objective to foment a duplication of the public transport in the international market up to 2025 when compared to the level of 2002. For this, the public transportation decision makers are focusing in actions towards improving their atractivity and efficiency capacity (AUDENHOVE, 1014).

The National Association of Public Transport (ANTP) also discusses the urbanization process. For this entity, the urbanization process that took place in recent decades and the geographical separation between residences and the places of social activities of work, education, health, security, commerce and leisure increased the demands for daily commuting of people and things in cities. However, the modern context of mobility, which adds the issue of sustainability, is not reduced only to understanding and equating the needs of moving people and things. It influences the experts and decision makers in urban transport to focus, in addition to fluidity in vehicle traffic, on aspects as greater efficiency in the current model of people transport, both individual and collective. Then, technology must incorporate solutions to improve the quality of travel for people who do not use or do not have cars, as well as to attract users of individual transport (ANTP, 2014).

The National Association of Urban Transport Companies (ANTU) understands that, superficially, when it comes to sustainable mobility, the meaning is related to moving people and goods in cleaner, greener, safer, healthier, more inclusive and equitable ways. Expanding on this issue, it means understanding transport as something that aims to meet the basic needs of people and the planet as a whole, regardless of whether these needs are of a social, environmental or economic nature. This conception expands the traditional view of mobility, focusing more specifically on transport infrastructure (ZIELINSKI, 2015).

Sustainable urban mobility actions, in addition to addressing the use of urban space, should also focus on reducing pollution caused by vehicles, increasing efficiency in energy consumption, replacing fossil energy sources with renewable sources and increasing efficiency and access to public transport (EPE-MME-DEA NT10/14, 2014; MME-EPE NT10/14, 2014; MME-EPE BEN 2014/2013; MME - EPE – NT14/13, 2014).

In Brazil, the Law N° 12,587 of January 3, 2012 (BRASIL, 2012) establishes the guidelines of the National Urban Mobility Policy, defining it as an organized and coordinated set of modes of transport, services and infrastructure that guarantee the movement of people and cargo within the territory of the Municipality. The same institute classifies the “Urban transport modes” as motorized, which uses self propelled vehicles, and non-motorized, which are the modes “that use human or animal traction effort”. The urban infrastructure, according to the same law, is formed by: roads (highways, subways, waterways and bicycle lanes); parking lots; terminals; stations and connections between modes; embarkation and disembarkation points; signaling devices; equipment and systems for traffic control, information dissemination and collection of fees and charges. And this entire infrastructure is built according to the specific characteristics of each urban agglomeration.

Traffic lanes are defined in the Brazilian Traffic Code (BRASIL, 1997) as a surface through which vehicles, people and animals transit and comprises the lane, the sidewalk, the emergency side lane, the median island and they are classified as Urban Roads, Rapid Transit Roads, Arterial Roads, Collector Roads, Local Roads, Rural Roads, Highways and Roads in general.

There are still other classifications for the transit routes present in documents such as: the Manual of Geometric Project of Urban Crossings of the National Department of Transport Infrastructure; the Master Plan for the Municipality of São Paulo; the Regional Strategic Plan of the Municipality of São Paulo and Ordinance 02/21-DSV/SMT of the São Paulo Traffic Engineering Company (FAJERSZTAJIN, 2012).

Regarding the type of collective transport dedicated to people who travel through urban region, there is not a single, optimal modal that can alone take care of the passenger load in the whole network. So, the transportation of people in large cities is done by a combination of modes dedicated to individual and collective transport, which complement each other forming then a single integrated multimodal system (VUCHIC, 2007).

Among the systems dedicated to collective urban transport, there are vans, common and electric buses, heavy subway, suburban trains and the medium capacity modes of transport known as Bus Rapid Transit (BRT), light subway, PRT (Personal Rapid Transit), VLP (Light Vehicle on Tires or GLT, Guided Light Transit) and Light Vehicle on Rail (LRT). The different systems available can be classified by type of use, by the segregation from different modes in the rolling infrastructure, by the technology used and by the types of services offered. By type of use, transport can be classified into private, rented and public. Private ones are those operated by the owners themselves and composed of cars, motorcycles or bicycles. The rented ones, also named by the authors in reference to paratransit, are the systems made available to users by transport service providers such as taxis or buses. These operate without fixed itineraries, which are designated by users. Public transport, or mass transport, operates with pre-established routes and schedules and is made available to the public upon payment of fees. As for the segregation of the circulation from other different modes in the transit lanes, the same expert classifies them into categories. Category A defines mixed traffic, with road and rail vehicles. In category B are the longitudinal corridors for exclusive traffic, with level crossings. And in category C are the longitudinal corridors for exclusive traffic without level crossings. And, due to the technology used, the systems differs each other in terms of: the type of contact between the vehicle and the roadway (tires and roadways; steel wheels and rails and vehicles guided either by devices installed on the transit lane or manually driven); the type of propulsion (electric or internal combustion engines) and the type of control that regulates the time schedule plan. Another difference indicated by the author concerns to the type of transport service offered: transport on short and dense routes; longer lines, with fewer stops and higher speeds; express interconnection between distant points, without intermediate stopping points and lines that interconnect urban agglomerations (suburban lines) (ALOUCHE, 2012; VUCHIC, 2007).

The BRT Manual (MINISTÉRIO DAS CIDADES, 2008, p. 53) classifies the technologies available for collective urban transport as: Bus Rapid Transit (BRT), a bus system operating in exclusive lanes; Light Rail Transit (LRT), technology also known in Brazil as Light Transit Vehicle (VLT), which operates with electric trains; Trams, which also operate with electric cars, but smaller than the LRT/VLT and circulate in shared traffic streets with the vehicles of the road system; Metro, which is a heavy system with trains that run on segregated and typically buried tracks; Suburban trains and the so-called Personal Rapid Transit (PRT), this one which is a system in which cars run on tires or tracks transporting people with small automatically guided vehicles. As for the feasibility of these technologies, the manual informs that all of them are viable and that the choices are inherent to local applications conditions and preferences are according to decision makers. The Monorail is another technology for urban transport that has existed for over 40 years with several applications in Japan and abroad (MINISTRY OF CITIES, 2008).

This brief introduction covered general aspects of the systemic definition of transport, energy intensity and efficiency in urban transport, the recent process of urbanization, sustainable urban mobility, the need to increase collective urban transport and transit routes and urban transport modes.

Follow now a description of the general characteristics of the three modes focused on in this work that are the BRT, LRT/VLT and Monorail. To the last one it is assigned the acronym MNT. The material covers aspects of definition, cost (investments and operation and maintenance), operational performance (energy efficiency, transport capacity and average operational speed), quality of service (interval between vehicles and safety), environmental impacts (noise level, visual aesthetics of the infrastructure and implementation time) and general characteristics of the vehicles. The specific cases mentioned do not exhaust the universe of applications of the three modes in focus, but those that could provide sufficient data for the development of this work were selected. Examples of international applications and projects that employ the three systems and also in Brazil are cited.

BRT

Definition

According to the BRT Manual (MINISTRY OF CITIES, 2008, p. 1), this is a national solution that has become a reference for applications in other cities abroad. The reference document defines BRT as “a bus transport system that provides fast, comfortable and cost-effective urban mobility through the provision of segregated infrastructure with travel priority, fast and frequent operation and excellence in marketing and user service”. The same source reports that the acceptability of BRT by users is linked to specific characteristics that it has, such as accessibility, security, integration with other modes, image of providing a safe environment throughout the system and user access to the own system status via information panels.

BRT is a transport system with buses that has infrastructure, vehicles and operational procedures, which provide a good quality service and is attractive to users. The acronym BRT was adopted in North America and gained worldwide acceptance. In Brazil, the BRT was developed in the city of Curitiba, starting in the 1970s, to equip the Express Bus axes and the Integrated Transport Network, starting operation on an exclusive lane in 1974 with the implementation of the first 20 km of exclusive lanes for Express buses in the city of Curitiba (LERNER, 2009).

The Institute for Transportation & Development Policy (ITDP) developed the BRT Standard document (ITDP, 2014; Annex IV), which is periodically revised and in which there is a common definition for the BRT modal. It is also a tool that can be used to recognize bus systems as BRT class and encourage decision makers from Muncipalities and manufacturers to consider in their planning the key requirements that define the modal. As an example, there are five criteria that qualify the BRT in the ITDP 2014 version: Road Infrastructure, which can be scored up to 7 rates; Segregation of Track Infrastructure, up to 7 rates; Ticketing Outside the Vehicle, maximum of 7 points; Intersection treatments, up to 6 points and Floors Alignment between the vehicle and platform, also up to 6 points. The scores for each criterion are obtained from the evaluation of the sub-criteria associated with them. The maximum score is 100. There are three score grades that qualify the system as a BRT modal: Gold, Silver and Bronze. At Gold level, the system has 85 points or more and attests it as meeting international standards for operational performance, efficiency and quality of service. At Silver level, the system has a score between 70 and 84 and is similar to Gold in terms of operational performance and quality of service. In Bronze, with a score between 69 and 70, the system is still considered a BRT, also achieving good operational performance and quality of service. The BRT Standard - 2014 defines a BRT corridor as a section of road or segregated lane served by one or even several bus routes with a minimum length of 3 km (1.9 miles) (ITDP, 2014). Traffic segregation is an essential element for the system to be efficient in terms of average speed, operational performance and quality of service. The Brazilian systems certified by the ITDP institute, with the 2013 version of the BRT Standard, are: Integrated Transport Network, Green Line, at Curitiba city (BRT Gold); TransOeste

Corridor, Rio de Janeiro (BRT Gold); Integrated Transport Network, North, South, East, and Boqueirão, Curitiba city (BRT Silver); Tiradentes Express, São Paulo (BRT Silver) and São Mateus Jabaquara Metropolitan Corridor, São Paulo (BRT Bronze).

Regarding infrastructure, BRT lanes are typically installed at the street level, although there are examples of partial or full elevated installations, such as stretches of the Expresso Tiradentes in São Paulo city (SPTrans, 2017), the Xiamen BRT in China (BRT Xiamen, 2008) and the BRT Sunway Line in Malaysia (BRT Sunway Line, 2015).

Cost

Investment

According to the Ministry of Cities (2008), the cost per km of the BRT is in the order of 4 to 20 times lower than the LRT or 10 to 100 times lower than a Heavy Metro system. In general, the cost of infrastructure is from 1 to 8 million dollars per km, not counting major expropriations, widening of the road and works of art.

The experience of Curitiba city shows that the cost of 20 km of BRT is R$ 140 million, considering an infrastructure composed of 6 integration terminals, 30 intermediate stations and a Signaling and Control system. In this example, the cost is R$7 million per km. The additional amount in vehicles is R$ 80 million, related to the cost of 80 bi-articulated buses or 134 articulated buses (LERNER, 2009).

For Alouche (2012), the cost per km of the BRT is in the range of R$34 to R$50 million. As an example, the BRT of the TransCarioca Line in Rio de Janeiro, with 39 km, was budgeted at R$ 1.83 billion, which represents R$ 47 million per km (BRT BRASIL, 2014).

Operation and maintenance

Operation and maintenance costs are composed by materials and labor and are difficult to generalize. The labor component is very dependent on local costs.

In Brazil, an example of the cost of operation and maintenance is the data of the BRT of the Curitiba city. These costs are estimated by Lerner (2009) at R$ 0.69 per passenger transported per day, including fixed costs (salaries and social charges, taxes and depreciation) and variable costs (operating energy, materials, third-party services and general expenses).

For greater São Paulo area, also in Brazil, there is the following information on operation and maintenance costs for public transport systems computed for the year 2012 and 2013: R$ 4.13 per passenger transported per day for the SPTrans municipal bus system (66.9% are fixed costs, 25.2% are variable and other costs are 7.9%); R$ 3.31 for the EMTU intercity bus system (74% for fixed and variable costs, with 30% for variable costs and 26% for others); R$ 2.62 for the CPTM suburban trains (64.8% for fixed and variable costs and 35.2 for others); and R$ 1.95 for the subway (heavy Metro) system (56% fixed; 23% variable, broken down into 13% for third-party services, 7% for traction energy consumption and 3% for materials and others, 21%). Note that the energy consumption for traction power represents between 7% and 30% of the variable costs for operation and maintenance of the vehicles (LOPES, 2013). For reference, the average American Dollar conversion rate in December 2013 is: 1,0 US$ equal 2,16 R$ (Source: ipeadata.gov.br).

Operational performance

Energy Intensity (IE) and Energy Efficiency (EE)

An energy efficiency estimate for the BRT is made below, restricted to the following assumptions: specific attention to the characteristics and operation of the vehicles; use of the l/p-km metric; articulated or bi-articulated vehicle, which consumes 61.7 liters (l) of diesel oil per hour (h) and has a maximum capacity to transport 235 passengers (p) (MERCEDES, 2016; SCANIA, 2011; VOLVO, 2016); full operation load, constant average speed of 35 km/h and one hour of travel. With these assumptions, the energy intensity (IE) of this vehicle to transport a person between points A and B, 35 km apart, is calculated with Equations 1 and 2 and the energy efficiency (EE) with Equations 3 and 4.

The BRT consumption in liters of diesel oil per hour (61.7 l/h) is calculated in detail in Annex III. The average transport capacity of the vehicle adopted in this example is also developed in the same annex.

- BRT Vehicle – Energy Intensity (l/p-km) - Calculation example.

$$IE = [61.7 (l/h)*1(h)/235(p)]/35(km) = [0.2625 (l/p)]/km = 0.0075 \text{ l/p-km} \quad (1)$$

- BRT Vehicle – Energy Intensity (Mj/p-km) - Calculation example.

$$IE = 0.0075 (l/p\text{-}km)*36 (Mj) = 0.27 (Mj/p\text{-}km) \quad (2)$$

- BRT Vehicle – Energy Efficiency (p-km/l) - Calculation example.

$$EE = 1/0.0075 \text{ p-kn/l} = 133.33 \text{ p-km/l} \quad (3)$$

- BRT Vehicle – Energy Efficiency (p-km/Mj) - Calculation example.

$$EE = 1/0.27 (Mj/p\text{-}km) = 3.703 \text{ p-km/Mj} \quad (4)$$

Transport capacity

The BRT can transport a large number of passengers adopting large capacity vehicles and operational strategies. Such strategies are: multiple stopping positions at stations; combination of express services with stops at few stations; leveling vehicle and station floors for boarding and disembarkation and pre-purchased tickets at stations. With these strategies, Curitiba's city BRT can transport up to 48,600 p/h/s (passenger hour direction), 16,200 on a stopping service and 32,400 on a direct service without stopping in all stations. In the city of Bogotá (Colombia), the BRT TransMilenio can transport 42,000 p/h/s. In Rio de Janeiro city, the TransCarioca Line is expected to transport 500,000 passengers per day, with 50,000 p/h/s during peak periods (BRTBRASIL, 2014; LERNER, 2009; MINISTÉRIO DAS CIDADES, 2008).

Average operating speed

The average operating speed (Vm) of most BRTs is between 23 and 39 km/h. The stopping time at embarkation and disembarkation points plays an important role in calculating this speed. The shorter this time, the greater the Vm. Items that contribute to minimizing this time are wide doors on vehicles, a pre-payment system for tariffs external to the vehicle and vehicle and stations floors leveling for boarding and disembarkation (MINISTÉRIO DAS CIDADES, 2008). Curitiba's city BRT has express and stopping lines. The express service can operate with Vm of up to 35 km/h and the stopping service up to 20 km/h (LERNER, 2009). For Alouche (2012), the BRT has Vm between 20 and 30 km/h.

Quality of Service

Interval between vehicles (headway)

With data from 2009 (LERNER, 2009), the BRT can operate with headways (time interval between vehicles) of about 60 seconds break on stopping lines and 30 seconds on express non intermediate stopping lines.

Safety

When operating in fully segregated lanes, the BRT vehicle is not mixed with the street traffic operating on the same road system. As the operation of the BRT vehicle is carried out in manual mode, the level of safety with accidents between BRT vehicles of the system itself and, or, between BRT vehicles and other vehicles, or even between BRT vehicles and maintenance personnel, level of safety relies on good driver's training and care with operational procedures.

Environmental impacts

GHG emissions

The BRT Manual (MINISTRY OF CITIES, 2008, p.6) reports that “Euro 3 emission levels are increasingly becoming the world standard”. And that “such clean vehicle technology includes: clean diesel, compressed natural gas, liquefied petroleum gas, biofuel, hybrid electric vehicle and trolleybus”.

The work done by LERNER (2009) reports that the BRTs in Rio de Janeiro and Curitiba have been using B5 diesel since 2006 (with 5% added biodiesel) and that 100% biodiesel was, at the time, being tested in articulated vehicles.

The BRT positively meets the indicators of sustainability and accessibility, economic feasibility and coordination between land use and collective urban mobility. However, the issue of the use of diesel oil remains and this is a topic that should be considered in the improvement of this system (CINQUINA, 2008). Other specialists, such as Alouche (2012), also understand that the emission of gases is an aspect of the BRT that must be addressed by manufacturers.

In the case study of this work, there are considered the average emission factor of 2.67 kgCO_2eq per liter of diesel fuel burned by the internal combustion engine of the BRT vehicle and the average factor of 0.5 kgCO_2eq for the production and distribution of 1.0 liter of diesel oil (AGRO ANALYSIS, 2009; CARVALHO, 2011).

Noise level

In São Paulo city, buses powered by internal combustion engines are subject to the SPTrans Norms, 2013, citing the ABNT standard NBR 9079, 1985 (BRASIL 1985). According to this standard, the noise level inside the vehicle must be less than 85 dB (A). Externally, the vehicle must not exceed the value stipulated in current environmental standards.

Aesthetic look of the infrastructure

The aesthetic look of the BRT track infrastructure, as well as the LRT and Monorail, is addressed subjectively as an assessment item. One aspect highlighted by experts on this criterion is the concern regarding a section division of the street, caused by introduction of segregated or semi-segregated corridors.

Deployment time

The BRT system can be well planned on time schedules between 12 to 18 months and, after this phase, built in a period of up to 3 years (MINISTÉRIO DAS CIDADES, 2008).

General vehicle characteristics

BRT vehicles (Figures 2, 3 and 4) can have lengths between 18 m and 30 m, up to 4 doors with leaves measuring 0.8 m, and capacity for 160 to 300 passengers, depending on the type of vehicle and occupancy rate (people/m^2). The rates of acceleration and deceleration are on the order of 1 m/s^2 (MADISON, 2013).

Engines use diesel oil as fuel. Citing some examples, the Scania bi-articulated vehicle operates with a 264 kW engine (360 hp at 2,000 rpm) and the Volvo engine produces 250 kW (340 hp, at 2,00 rpm). The Mercedes vehicle engine articulated is equipped with an engine with a power of 260 kW (354 hp), also at 2,000 rpm; the declared specific consumption is 184g/kWh, at 2,000 rpm. Vehicle weights are 30,000 kg with a load of 165 passengers for articulated vehicles and 40,500 kg with 250 passengers for bi-articulated models.

Figure 2 - Scania Bi-articulated F340 HA.
Source: Scania[1].

1. Available at: <https://www.scania.com>.

Figure 3 - Super-articulated Mercedes 500 MDA HD.
Source: Mercedes-Benz[2].

Figure 4 - Gran Artic 300 Bi-articulated Volvo.
Source: Volvo; Nova Bus – 2012[3].

2. Available at: <https://www.mercedes-benz.com.br>.
3. Available at: <http://www.novabus.com/october-2012/volvo>.

LRT

Definition

The VLT has the same objective as the BRT, in the sense of providing a service of good quality and attractiveness to users, but it differs from that in the sense that this employs infrastructure and vehicles with railway characteristics.

This mode of transport is derived from trams. It was introduced in France in the 90s, adopted in North American cities and currently has a presence in several cities in several countries, among others: Germany; Australia; Spain; England; Ireland and Portugal. In the United States they are known by the term *light rail*. In Brazil, the term LRT has been known since the 1980s. (ALOUCHE, 2006; ALOUCHE, 2012; LERNER, 2009).

The LRT technique is defined as,

> "(...) technology based on electric trains, either with a single car or with a short composition of cars, typically running in exclusive lanes with right-of-way at street level with electrical power connections over the entire length of the line" (MINISTÉRIO DAS CIDADES, 2008, p. 53).

The LRT is a solution with lower transport capacity and lower investment cost when compared to heavy Metro. The main features of the system are: operation in segregated right of way; ease of access (friendly accessibility); good popular acceptance; ability to attract users to the public transport system; energy efficiency; environmentally correct; regularity of travel and comfort (PLANUS, 2015).

For the VTA (California, Santa Clara) Authority, the tramway is a high-quality, affordable system, capable of providing an accessible and convenient service to attract and promote development around its stations and along the transport corridor. In the VTA system, the distance between stations is on the order of 800 m to 1500 m. The line can have the options of sharing traffic with the road or being semi or completely segregated; it also has tunnels and elevated parts. To promote attractiveness and at the same time provide competitive travel times, the routes were designed to connect central points of the city with service centers along arterial roads. Shared circulation at central points reduces average operational speed and safety, but when operating on semi or fully segregated lanes travel it is faster and safer. In the VTA system, tickets are purchased at points of sale outside the vehicle (VTA, 2007).

The tramway is "a rail-guided metro system, characterized by its ability to operate single vehicles or short trains on dedicated lanes at ground level, in overhead structures, below the surface, or, occasionally, on streets and embark people on platforms aligned or not with the floor of the vehicle" (BOORSE, 2000).

Alouche (2006; 2012) indicates two concepts for the application of the LRT: the LRT at level, with partial segregation and traffic lights pass way prioritization and the LRT with total or partial segregation, in an elevated infrastructure. The author cites classic examples of elevated or partially elevated LRTs in his article: Monterrey LRT (Mexico); Dallas Light Rail (USA) and Docklands Light Rail (England).

In Brazil, the LRT is being implemented at level, with traffic lights priority, planned to be deployed in phases, in Rio de Janeiro city and in Baixada Santista (Santos city). It is also planned for the cities of Campinas, Cuiabá, Florianópolis, Fortaleza, Goiânia, Natal, João Pessoa, and Petrolina (REVISTA FERROVIÁRIA, 2015).

Cost

Investment

The investment cost in the LRT is 3 to 4 times higher than the cost of a BRT system (PLANUS, 2015).

The LRT in Rio de Janeiro, under deployment in the port area as a revitalization project, has an infrastructure cost estimated at R$ 43 million per km. The 22 trains planned are funded by private partners (PREFEITURA-RIO-SECPAR, 2016).

The cost of the Santos tramway infrastructure is estimated at around R$ 60 million per km. It is 23.4 km long, with an estimated budget of R$ 1.4 billion for projects and infrastructure. The 22 trains planned for the system are funded by the private sector partners, on a PPP project model (EMTU (a), 2013; EMTU (b), 2013).

According to Alouche (2012), the cost of the VLT is around R$ 65 to R$ 100 million per kilometer (1,0 US$ = R$ 1,95 – source: ipeadata.gov.br.

For reference, the average Brazilian Reais (R$) conversion value to one (1,0) US Dollar (US$) are: December 2012, R$ 1,95; December 2013, R$ 2,16; December 2015, R$ 3,33; December 2016, R$ 3,49. (source: ipeadata.gov.br).

Operation and maintenance

The operational costs of the LRT, like the BRT, vary from region to region because they are composed not only of materials and spare parts, which can be valued according to international standards, but also with local (regional) costs such as labor costs, energy and working (job) infrastructure. The value of US$ 0.22 per transported passenger is adopted in this work, according to the calculation memorial described in Annex III.

Operational performance

Energy Intensity (EI) and Energy Efficiency (EE)

The cases of Baixada Santista (Santos city, in São Paulo State) and Rio de Janeiro are used below to characterize the energy efficiency of the LRT vehicles of these systems. For the purpose of comparison with the BRT vehicle, the same metric for energy intensity and average operational speed is maintained in this calculation.

Each Santos LRT train has the capacity to transport 400 passengers with a density of 6 passengers per m^2 and has 6 electrical motors of 105 kW each, totalizing a power capacity of 630 kW (EMTU (a), 2013; EMTU (b), 2013; VOSSLOH, 2016).

The train of the LRT in the Rio de Janeiro system also has the capacity to transport 400 passengers, with a density of 6 passengers per m^2 and is driven by 6 motors of 175 kW each, which results in a total power of 1,050 kW (ALSTOM, 2017; PREFEITURA-RIOSECPAR, 2016).

For an example of Energy Intensity and Efficiency calculation, let's set the assumptions: average system operating speed of 35 km/h; the kWh/p-km metric for energy intensity (VUCHIC, 2007); the energy efficiency of the vehicle operating at full passenger load; transport between two points A and B distant 35 km each other. With these assumptions, the Energy Intensity (IE) of the Santos VLT, to transport a person between two points A and B 35 km apart, is given by Equations 5 and 6 and the energy efficiency (EE) by Equations 7 and 8:

- Santos LRT Vehicle (Vossloh) - Energy Intensity (kWh/p-km) - Calculation example.

IE = [630 kWh/400(p)]/35(km/h) = [1.575kWh/p-km)]/35km/h = 0.045 kWh/p-km (5)

- Santos LRT Vehicle (Vossloh) - Energy Intensity (Mj/p-km) - Calculation example.

IE = 0.045 (kWh/p-km)*3.6 (Mj) = 0.162 (Mj/p-km) (6)

- Santos Light Rail Vehicle (Vossloh) - Energy Efficiency (1/kWh/p-km) - Calculation example.

EE = 1/0.045 kWh/p-km = 22.222 p-km/kWh (7)

- Santos Light Rail Vehicle (Vossloh) - Energy Efficiency (l/Mj/p-km) - Calculation example.

EE = 1/0.162 (Mj/p-km) = 6.173 p-km/M (8)

Following the same calculation approach, the Rio de Janeiro LRT vehicle has the following energy performance to perform the same transport work, calculated through

Equations 9, 10, 11 and 12:

- RJ Light Rail Vehicle (Alstom) - Energy Intensity (kWh/p-km) - Calculation example.

IE = [1,050 kWh/400(p)]/35(km/h) = [2.625kWh/p)]/35km/h = 0.075kWh/p-km (9)

- RJ Light Rail Vehicle (Alstom) – Energy Intensity (Mj/p-km) - Calculation example.

IE = 0.075 (kWh/p-km)*3.6 (Mj) = 0.27 (Mj/p-km) (10)

- RJ Light Rail Vehicle (Alstom) – Energy Efficiency (l/kWh/p-km) - Calculation example.

EE = 1/0.075 kWh/p-km = 13.333 p-km/kWh (11)

- RJ Light Rail Vehicle (Alstom) – Energy Efficiency (l/Mj/p-km) - Calculation example.

EE = 1/0.270 (Mj/p-km) = 3.704 p-km/Mj (12)

Note the similarity of values between the examples of the BRT and the LRT vehicle in Rio de Janeiro (both similar EE figures, around 3.703 p-km/Mj).

Table 1 summarizes the energy efficiencies of Vossloh and Alstom vehicles. Note, these results are valid numbers for the assumptions adopted for calculations.

MANUFACTURER	OPERATIONAL CHARACTERISTICS	IE (Mj/p-km)	EE (p-km/Mj)
VOSSLOH	5 cars; 400 p; 630 kWh	0.162	6.173
ALSTOM	5 cars; 400 p; 1050 kWh	0.270	3,704

Table 1 - Energy Efficiency of VLT Vehicles.
Source: VOSSLOH and ALSTOM; data adapted by the author.

Transport capacity

The Baixada Santista (Santos city) the LRT system is estimated to meet a passenger load of 70,000 people per day, with an average flow of 7,000 passengers per hour per direction, with a semi-segregated lane infrastructure (EMTU (a), 2013; EMTU (b), 2013).

The estimate of the study done by the Brazilian Ministry of Transport is that the LRT can serve an average transport flow of up to 20,000 passengers per hour and per direction (phs) (MINISTÉRIO DAS CIDADES, 2008).

According to the study done by Planus (2015), due to limitations such as braking rate and the inability of vehicles to operate in the same single line combining services like express and trains stopping in all stations, the transport capacity of the LRT system is limited to 20 thousand phs, with minimum intervals between vehicles of 3 or 4 minutes.

However, regarding to acceleration and braking rates, such rates, as reported by the LRT vehicle manufacturers, they are equivalent to the rates of rail vehicles used even in high-capacity systems, such as subways (author's note).

In general, experts and operators characterize the LRT as an alternative for applications with loads between 20,000 and 25,000 phs (passenger hour direction) (LERNER, 2009).

Other decision makers involved with LRT systems define their transportation capacity in the range of 15,000 to 35,000 phs (ALOUCHE, 2012).

The Rio de Janeiro LRT has an estimated load of 300,000 passengers per day, with 20,000 to 30,000 p/h/s and it is designed for semi-segregated operation (PREFEITURA-RIO-SECPAR, 2016).

It is interesting to note that there are examples of Authorities that far exceeds the limits above mentioned, as the case of the Manila Light Rail, which transports 500,000 passengers a day on Line 1 and 200,000 on Line 2. In rush periods Line 2 reaches the mark of more than 50,000 phs (RAILWAY-TECHNOLOGY, 2017; REVOLVY, 2017; SYSTRA, 2017).

The LRT has also the ability to couple and uncouple vehicles, which results in trains capable of carrying around 800 passengers at peak intervals. With this possibility, the transport capacity of the LRT is closely linked to the number of vehicles available (author's note).

Average operating speed (Vm)

The bibliography consulted attributes to the LRT the average operational speed range between 18 and 40 km/h. This range varies mainly depending on the rolling infrastructure design and on operating strategies.

In the feasibility study of the LRT for Florianópolis city in Brazil, the Vm is established between 18 and 22 km/h, operating on a semi-segregated lane (PLANUS, 2015).

On the Santos LRT, the Vm is estimated at 25 km/h, with vehicles traveling on a semi-segregated lane with traffic light priority (EMTU (a), 2013; EMTU (b), 2013).

In the VTA system, the minimum operational Vm is 37 km/h, with fully segregated lane infrastructure (VTA, 2007).

The VLT in Rio de Janeiro estimates a Vm between 20 and 40 km/h. The system operates on a shared lane with cars and buses, but with traffic light priority (PREFEITURA-RIO-SECPAR, 2016).

On the Manila tramway, the average speed is 40 km/h on a fully segregated track (RAILWAY-TECHNOLOGY, 2017; REVOLVY, 2017; SYSTRA, 2017).

Considering the above cases, it is possible to see the average speed offered by the LRT ranging from 18 to 40 km/h. Full or partial segregation of the trains plays an important role.

Quality of Service

Interval between vehicles (headway)

The interval between vehicles must be studied on a case-by-case basis and depends on the infrastructure segregation level, average operating speed, vehicle braking and acceleration rates, loading and unloading time and operator skill, as the LRT trains are manually operated.

Safety

The level of safety of the LRT considering accidents between trains and vehicles of the street traffic is a function of: the degree of segregation of the infrastructure; the trackside and onboard signaling warns available for the train operator in case of partial segregation; and expertise of the train operator acquired in training and application of the operational procedures of the Authority.

Environmental impacts

GHG emissions

In general, the consulted bibliography is unanimous in informing that electric rail systems are more efficient and less polluting than public road transport systems (ALOUCHE, 2012; BOORSE, 2000; MINISTÉRIO DAS CIDADES, 2008; PLANUS, 2015).

In the case study of this work, it is used the average emission factor of 81.7 $kgCO_2eq$ per MWh consumed from the SIN (Electrical National Interconnected System). This index is published by the Brazilian Ministry of Science and Technology (MCT, 2017) for 2016.

Noise level

In addition to the issue of air emissions, electric vehicles are also less noisy than buses, which use internal combustion engines. The maximum levels of noise permissible in Brazil for internal and external environments to trains and trams, for collective urban transport, are governed by the ABNT NBR 13068 Standard. In the passenger interior lounge, the sound pressure level (Leq) must be, at the maximum, 64 dB (A) for a stationary vehicle;

near to the driver, of 75 dB(A) and, far from him, of 80 dB(A), with the vehicle traveling at 60 km/h. Outside the vehicle, the levels must be 80 dB (A), with the vehicle stationary; with the train departing, 85 dB (A) and, traveling at 60 km/h, 90 dB (A) (ABNT NBR, 1994; EMTU (a), 2013; EMTU (b), 2013).

Aesthetic look of the infrastructure

In general, subjectively, the LRT is seen by specialists in urban transport as a system that integrates well into the urban environment, attracts users and gives to the city a positive image (ALOUCHE, 2012).

Deployment time

The LRT can be installed and commissioned in sections. In the cases of the Santos and Rio de Janeiro LRTs, the first sections were planned to be delivered in times in the order of 3 to 4 years, after planning (EMTU (a), 2013; EMTU (b), 2013; CITY HALL-RIOSECPAR, 2016).

General vehicle characteristics

The length of LRT trainsets can be adjusted by coupling more than one minimum unit for the system to respond to changes in demand and operating speeds. In the VTA system, for example, a minimum composition has 3 cars of 27 m in length each and can accommodate up to 690 passengers (VTA, 2007).

In the case of Baixada Santista, the LRT vehicle (Figure 5) can serve up to 400 passengers, with a density of 6 passengers per m^2. The trainset consists of five cars and has a length of 44 m. Head carriages have a 0.8 m wide door on each side and intermediate carriages have two 1.3 m wide doors on each side. Each train is driven by 6 engines of 105 KW, fed with a voltage of 750 Vdc. Acceleration and deceleration rates are 1.2 m/s^2 (EMTUa, 2013; EMTUb, 2013; VOSSLOH, 2016).

The train of the LRT in Rio de Janeiro, in turn (Figure 6), consists of five cars, is 52 m long and has a capacity to transport 400 passengers, with a density of 6 passengers per m^2. Head carriages have a 0.8 m wide door on each side and intermediate carriages have two 1.3 m wide doors on each side. Each train of 5 cars is driven by 6 motors of 175 KW each, supplied with a voltage of 750 Vdc. The vehicle has an acceleration rate of 1.1 m/s^2 and deceleration of 2.5 m/s^2 (PREFEITURA-RIOSECPAR, 2017; ALSTOM, 2017).

Figure 5 - Light Rail - Santos.
Source: Viatrolebus, 2015[4].

Figure 6 - Light Rail - Rio de Janeiro
Source: Rio I go, 2016[5].

4. Available at: <http://www.viatrolebus.com.br/2015>.
5. Available at: <http://www.rioigo.com/2016>.

Monorail

Definition

The Monorail Society entity has the following definition for the Monorail system,

> "Monorail is a single track system with vehicles for the transport of passengers or cargo. In most cases the track is elevated, but monorails can run at street level, above the street or in underground tunnels. Vehicles can be suspended or with bogies that cling to a narrow guide beam. The vehicles are wider than the beam that supports them." (THE MONORAIL SOCIETY (b), 2017).

The suspended system is known as SAFEGE, denomination of the French company that developed this technique. It is also named as type *Suspended*. In this type, the vehicle runs suspended under the guide beam (SKYTRAINCORP, 2017).

The system in which the vehicle slides over the guide beam is known as ALWEG, an acronym for the German company that consolidated this type of monorail. It is also named type *Stranddle* (SKYTRAINCORP, 2017).

The ALWEG type Monorail emerges as a medium-capacity means of transport in urban areas in Brazil. It is being installed in phases on Line 15 of the São Paulo Metro and is planned for lines 17 and 18, also from the same operator (REVISTA FERROVIÁRIA, 2015).

Although new in Brazil, the Monorail is in operation in dozens of cities in countries such as Australia, Belgium, Canada, China, Finland, Germany, India, Ireland, Italy, Japan, Malaysia, Mexico, Russia, Singapore, Korea, Spain, Thailand and the United States. China and Japan are the countries with the most of installations of this type of mode (THE MONORAIL SOCIETY, 2017; JAPAN MONORAIL ASSOCIATION, 2016; WIKIPEDIA.ORG, 2017).

Monorail vehicles typically travel on guide beams installed elevated in relation to the street road system.

Cost

Investment

Based on nine designs supplied by manufacturers as Hitachi, Bombardier and Scomi between 1964 and 2008, *The Monorail Society* reports costs between US$15mi and US$88mi per km for the ALWEG type Monorail system (THE MONORAIL SOCIETY (a), 2017).

Another source reports that, in general, the average cost of the ALWEG system is US$ 70 mi/km. The same source puts the costs of Hitachi systems of this model between US$ 27 and US$ 73 mi/km and some systems from the manufacturer Scomi between US$

27 and US$ 36 mi per km (MONORAILS AUSTRALIA (a), 2017).

The three ALWEG-type systems, planned for installation in the city of São Paulo, under the responsibility of Metrô, have estimated costs of US$ 90 mi/km (Line 15 Silver: 24.5 km), US$ 53 mi/km (Line 17 Gold: 17.7 km) and US$ 84.7 mi/km for line 18 Bronze (15.7 km) (REVISTA FERROVIÁRIA, 2015; ROCHA, 2016).

Operation and maintenance

As with the LRT, the operational costs of the MNT also vary from region to region because they are linked to local costs. In this research, the value of US$ 0.20 per transported passenger is adopted, according to the calculation memorial described in Annex III.

Operational performance

Energy Intensity (IE) and Energy Efficiency (EE)

Examples of energy efficiency for three types of vehicles are shown as follow, maintaining the energy efficiency metric and operating speed of 35 km/h, as in the examples made for the BRT and LRT.

Hitachi vehicle

Hitachi vehicle: 4 car model; 560 p (140 p/car) and 720 kW of power (4 engines of 180 kW) (KUWABARA et al, 2001; SHAOXUAN et al, 2008). Equations 13, 14, 15 and 16 show the IE and EE for this vehicle.

- Hitachi MNT Vehicle - Energy Intensity (kWh/p-km) - Calculation example.

IE = [720 kWh/560(p)]/35(km/h) = [1.29 kWh/p)]/35km/h = 0.037 kWh/p-km (13)

- Hitachi MNT Vehicle - Energy Intensity (Mj/p-km) - Calculation example.

IE = 0.037 (kWh/p-km)*3.6 (Mj) = 0.132 (Mj/p-km) (14)

- Hitachi MNT Vehicle - Energy Efficiency (1/kWh/p-km) - Calculation Example.

EE = 1/0.037 kWh/p-km = 27.03 p-km/kWh (15)

- Hitachi MNT Vehicle - Energy Efficiency (1/Mj/p-km) - Calculation example.

EE = 1/0.132 (Mj/p-km) = 7.58 p-km/Mj (16)

Scomi vehicle

Scomi MNT vehicle: 4 car model; 484p (121p/car) and 800 kW of power - 4 engines of 200 kW for each train (SCOMIRAIL, 2017).

The equations 17, 18, 19 and 20 show the IE and EE figures for this vehicle.

- Scomi MNT Vehicle – Energy Intensity (kWh/p-km) - Calculation example.

IE = [800 kWh/484(p)]/35(km/h) = [1.653 kWh/p)]/35km/h = 0.047 kWh/p-km (17)

- Scomi MNT Vehicle - Energy Intensity (Mj/p-km) - Calculation example.

IE = 0.047 (kWh/p-km)*3.6 (Mj) = 0.17 (Mj/p-km) (18)

- Scomi MNT Vehicle - Energy Efficiency (1/kWh/p-km) - Calculation example.

EE = 1/0.047 kWh/p-km = 21.28 p-km/kWh (19)

- Scomi MNT Vehicle - Energy Efficiency (1/Mj/p-km) - Calculation example.

EE = 1/0.17 (Mj/p-km) = 5.88 p-km/Mj (20)

Bombardier vehicle

Bombardier MNT vehicle: 7-car model; 1001 p (143 p/car) and 1400 kW of power - 14 electric motors of 100 kW each (BOMBARDIERTRANSPORTATION, 2017).

The equations 21, 22, 23 and 24 show the estimations of IE and EE for this vehicle.

- Bombardier MNT Vehicle - Energy Intensity (kWh/p-km) - Calculation example.

IE = [1400 kWh/1001(p)]/35(km/h) = [1.398kWh/p)]/35km/h = 0.040kWh/p-km (21)

- Bombardier MNT Vehicle – Energy Intensity (Mj/p-km) - Calculation example.

IE = 0.040 (kWh/p-km)*3.6 (Mj) = 0.14 (Mj/p-km) (22)

- Bombardier MNT Vehicle – Energy Efficiency (1/kWh/p-km) – Calculation example.

EE = 1/0.040 kWh/p-km = 25.00 p-km/kWh (23)

- Scomi MNT Vehicle – Energy Efficiency (1/Mj/p-km) – Calculation example.

EE = 1/0.140 (Mj/p-km) = 7.143 p-km/Mj (24)

Table 2 summarizes the energy efficiencies of Hitachi, Scomi and Bombardier vehicles. Always remembering, numbers are valid for the adopted assumptions for calculations.

Manufacturer	Operational Characteristics	IE (Mj/p-km)	EE (p-km/Mj)
HITACHI	4 cars; 560 feet (140 feet/car); 600 kWh	0.132	4,000
SCOMI	4 cars; 484 feet (121 feet/car); 800 kWh	0.170	5,263
BOMBARDIER	7 cars; 1001 feet (143 feet/car); 1400 kWh	0.144	7,143

Table 2 - Energy Efficiency of Monorail Vehicles.
Source: Hitachi, Scomi and Bombardier; data adapted by the author.

Transport capacity

The Monorail serves an average transport flow of around 25,000 to 138,000 passengers per day with rates from 10,000 to 24,000 phs. These numbers depend on the characteristics of the track infrastructure, the capacity of the trains which can operate with 2, 4 and 8 cars, the rates of acceleration and deceleration and the level of automation of the on-board and trackside systems to control the offer of trains per hour. There are examples of high transportation loads, such as the systems in the cities of Chongqing (China) which expands the operation to serve more than 500,000 passengers per day and the one in São Paulo, whose Line 15 is expected to carry around 500,000 passengers a day and, at peak periods, predicted for go up to 48,000 phs (CICHINELLI, 2013; MECA, 2011; MONORAILS AUSTRALIA (a), 2017; JAPAN MONORAIL ASSOCIATION, 2016).

Average commercial speed

The systems in Japan travel with average speeds of the order of 26 km/h to 56 km/h. On Line 15 of the São Paulo Metro, the system is designed to operate with a minimum average speed of 35 km/h (JAPAN MONORAIL ASSOCIATION, 2016; MECA, 2011).

Quality of Service

Headway (time interval between trains)

The Monorail can meet headways of up to 90 seconds, as is the case of Line 15 of the São Paulo Metro. Similar to the operation of other systems, the range of headway of the MNT system is 1.5 to 3 minutes at peak periods.

Safety

As it operates on a segregated and elevated lane, the MNT vehicles are not involved with the road traffic. Added to the fact that most of the MNT systems can operate in full automatic mode or even having systems supervising a manual driving operation, the level of safety related to accidents between MNT vehicles is very high, meeting the standards of traditional railway systems.

Environmental impacts

GHG emissions

In terms of emissions, the monorail uses electricity, and therefore does not emit pollutants in the city (PLANUS, 2015; ALOUCHE, 2012).

In a similar way to the LRT, in the case study of this work the average emission index used is 81.7 kgCO_2eq per MWh consumed from the SIN (Interconnected Electrical National System) system. This index is periodically published by the Ministry of Science and Technology (MCT, 2017) and the value adopted was published in 2016.

Noise level

In applications ongoing in São Paulo, the Monorail follows the same standard for trains and LRTs applicable, both for to collective urban transport (ABNT NBR 13068 (BRASIL, 1994). As the Monorail uses wheels with rubber tires, it is considered a very quiet system.

Aesthetic look of the infrastructure

The elevated guide beams of an ALWEG type monorail system is very narrow and allows good passage of sunlight (Figure 7). Although it is less invasive than the infrastructure of a conventional system, with concrete platform that covers the sunlight (Figure 8), it draws the attention for being suspended in relation to the street and supported by pillars (MONORAIL SOCIETY, 2017).

The invasion of the urban landscape by the Monorail infrastructure is subject of discussions and the solutions that builders adopt to harmonize the pillars and the street level space of the environment is to use vegetation (Figures 9 and 10) (MONORAIL SOCIETY, 2017).

Figure 7 - Shading caused by the beams of a Monorail type ALWEG.
Source: (MONORAILS AUSTRALIA (a), 2017).

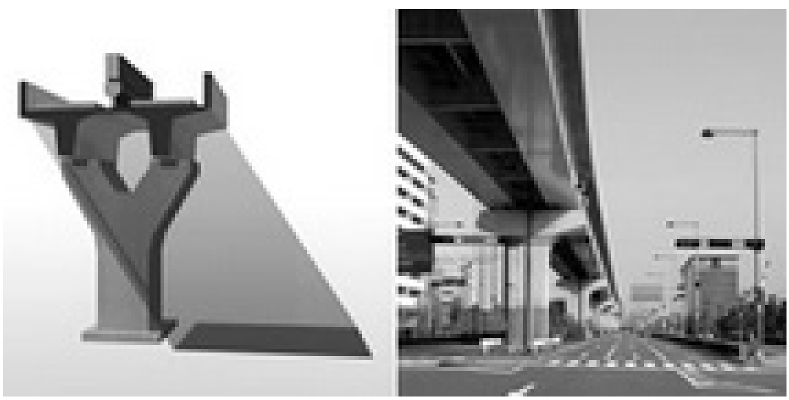

Figure 8 - Shading caused by the infrastructure of a conventional system.
Source: (MONORAILS AUSTRALIA (a), 2017).

Figure 9 - Las Vegas Monorail, USA.
Source: MONORAIL SOCIETY, 2017.

Figure 10 - Kitakyushu Monorail, Japan.
Source: MONORAIL SOCIETY, 2017.

A positive point of the elevated infrastructure is that it does not cause disturbances in the city in relation to the barrier effect for the streets and in relation to the occupation of highways. Another positive point is that the vehicles emit low noise levels, both inside and around the system, due to the use of rubber tires.

Deployment time

The Monorail has relatively quick installation time and little interference with local road traffic during this period. This is very advantageous when urban density is high and there is the possibility of harming local businesses by the prolonged construction of systems such as LRTs and Metro (s) (PLANUS, 2015).

The rolling beams are pre-molded in shipyards and installed in columns built in the central or lateral lanes of the traffic lanes, with hydraulic jacks, at scheduled times such as at night and on weekends. In the case of São Paulo Line 15, MNT, the first phase, with the stations Vila Prudente and São Mateus and approximately 10 km of track, were installed in about 24 months (MECA 2013).

General vehicle characteristics

Mitsubishi company manufactures suspended-type monorails (SAFEGE – Figure 11). In Asia there are systems of this type installed in Japan, in the cities of Chiba, Shonan and Tokyo. The minimum vehicle unit is formed by 2 conjugated cars and can be coupled with other units. The minimum vehicle measures 15.4 m in length and has the capacity to carry up to 80 passengers. Each car has two doors on each side, 1.8 m wide. It uses 2 motors of 65 kW, fed with 1500 Vdc. Acceleration and deceleration (service) rates are 1.0

m/s^2 (JAPAN MONORAIL ASSOCIATION, 2016; MITSUBICHI HEAVY INDUSTRIES, 2017; MONORAILS AUSTRALIA (b)).

The ALWEG MNT type (Figure 12), that has more applications, is produced by Hitachi, Scomi and Bombardier (MONORAILS AUSTRALIA (a), 2017; MONORAILS AUSTRALIA (b), 2017). In Brazil, the São Paulo Metro is using Bombardier vehicles on Line 15.

Figure 11 - MNT SAFEGE Mitsubishi.
Source: Monorails Australia[6].

Figure 12 - MNT ALWEG Bombardier.
Source: Author, 2016[7].

The Hitachi Company manufactures small, medium and large vehicles, which can be formed with 2, 4 and 8 cars. With a density of 6 passengers per m^2, the models can carry a maximum of 62, 130 and 150 passengers per car. Each car has two doors on each side, 1.0 m wide. The train made up of 4 cars, 60 m long, is powered by 12 motors of 105 kW each, powered by 1,500 Vdc. Acceleration (service) rate is 1.1 m/s^2 and deceleration 1.25 m/s^2 (SEKITANI, T. et al., 2005).

The Bombardier vehicle holds 143 passengers per car, with a density of 6 passengers per m^2. The train has 14 motors of 100 kW each, powered by 750 Vdc. The composition consists of seven cars and has a length of 90 m. Each car has two doors on each side,

6. Available at: <http://www.MonorailsAustralia.com.au>.
7. Author’s personal collection.

1.6 m wide. Acceleration and deceleration (service) rates are 1.0 m/s^2 (BOMBARDIER TRANSPORTATION, 2017; MECA, 2011).

The Scomi vehicle holds 121 passengers per car, with a density of 6 passengers per m^2. The composition can be formed with 2, 4 and 6 cars with respective lengths of 24.5 m, 46 m and 67.7 m. On the São Paulo Metro lines, the compositions planned by this manufacturer will operate with 4 cars. Each car has two doors on each side, 1.0 m wide. The 4-car train uses 6 motors of 150 kW each, powered by 750 Vdc. Acceleration and deceleration (service) rates are 1.1 m/s^2 (SCOMI RAIL, 2017; STRUKTONRAIL, 2017).

Comments

Follow a summary of the data present.

For the Energy Intensity (IE) criterion, the analysis is restricted to the power consumption of the vehicles with the metric of energy consumed per passenger per km (VUCHIC, 2007). Using the parameters of power consumption as declared by vehicle suppliers and average operating speed of 35 km/h, constant for one hour, the estimated values are: 0.270 Mj/p-km for the BRT; for the LRT, a range from 0.162 Mj/p-km (Vossloh) to 0.270 Mj/p-km (Alstom); and a range from 0.132 Mj/km (Hitachi) to 0.170 Mj/p-km (Scomi) for the MNT. The Energy Efficiency criterions are, respectively, 3.703 p-km/Mj for the BRT, a range of 3.704 to 6.173 for the LRT and a range of 4.00 to 7.143 p-km/Mj for the MNT (Table 3).

MODAL	IE (Mj/p-km)	EE (p-km/Mj)
BRT	0.270	3,703
LRT	0.162 to 0.270	3.704 to 6.173
MNT	0.132 to 0.170	4,000 to 7,143

Table 3 - Energy Efficiency of BRT, VLT and MNT Vehicles.

For the indicator *investment cost*, based on the sources consulted, in millions of reais (R$mi) per km, the ranges are from 10 to 40 for BRT applications, between 40 and 100 for the LRT and 50 to 300 for the Monorail. (Chart 2).

Operation and maintenance costs depend on local variables and must be calculated in specific cases. Using the metric of cost per passenger transported per day, it was possible to identify the figures (in Brazilian Reais) of R$ 0.69 (LERNER, 2009), R$ 0.22 (author's estimate) and R$ 0.20 (author's estimate), respectively for BRT, LRT and MNT.

Transport capacities are in the range of 10 and 49 thousand passengers per hour per direction (Chart 2). The three modes have vehicles with very close acceleration and deceleration capabilities, in the range of 1.0 m/s^2 to 1.25 m/s^2. These values give to the three modes a very similar performance in terms of approach and departure times at points of embarkation and disembarkation of passengers. These variables are important to run trip performance simulations with software programming tools (author's note).

As for the average operating speed, the BRT and LRT are able to operate with average speeds between 20 and 35 km/h. The Monorail serves a slightly higher range, with an average operating speed between 25 and 50 km/h (Chart 2).

Interval between trains (headway) and security are parameters that must be evaluated in specific case studies.

Regarding environmental emissions, the BRT is questioned for using fossil fuel, a point that has encouraged manufacturers to develop engines to burn renewable fuels. The LRT and MNT technologies are praised for the use of electric motors, because they do not emit pollutants in the region where they operate. In this regard, emissions can occur in the region where the electricity is generated if fossil fuel is used for this purpose, and is something that cannot be neglected (author's note). In terms of internal and external noise to the vehicle, the MNT has better performance. Implementation time and disturbances caused in the surroundings of the projects during the deployment period are requirements that favor BRT and MNT technologies.

This brief characterization of the modes under analysis shows that there is a large amount of technical information available on the three alternatives under study. Some, such as investment costs, transport capacity and operating speeds, can be considered general objective variables and can be easily quantified from data provided by manufacturers and consultants of the transport sector. Others need to be qualified and quantified in specific cases. And, a third category, are the variables that need to be evaluated subjectively. In addition to the technical performance of the alternatives, the decision maker needs support processes and tools to structure such information together with others of the concrete case. The concrete case must consider the preferences of local decision-makers, specific needs as the geography of the region, trip networks specifics as well as local political and financial priorities.

The bibliographic research continues with the analysis of the methods applicable to decision making in so-called complex problems, which involve the evaluation of multiple criteria, multiple decision agents and more than one possible technical alternative solution.

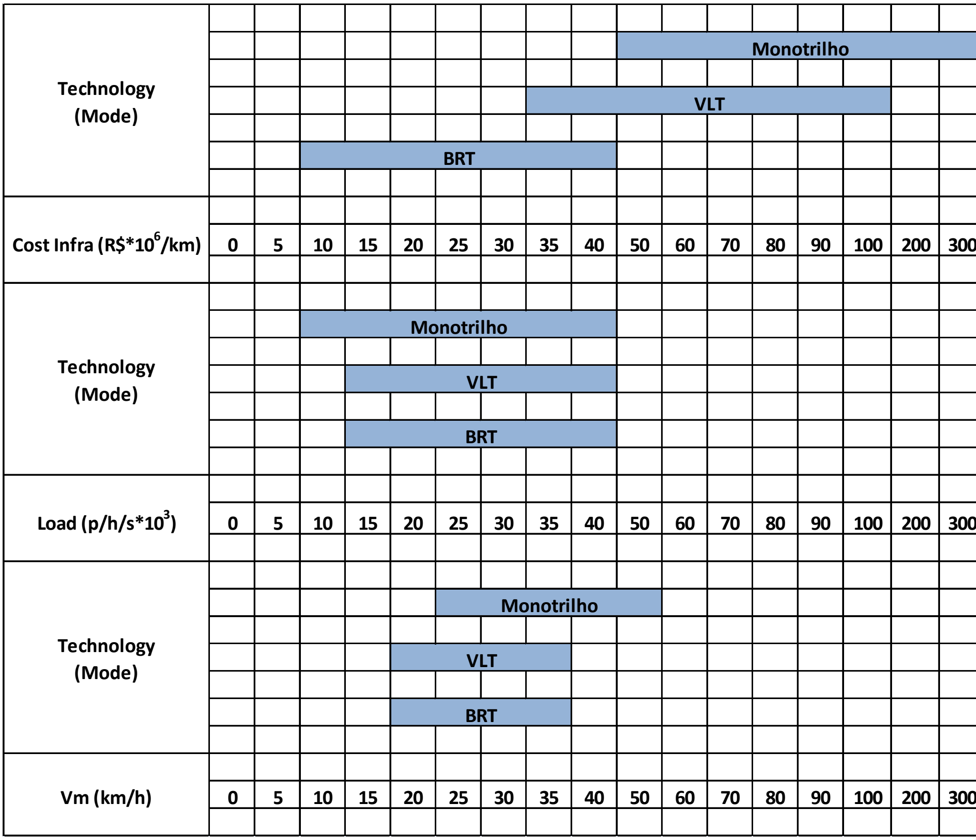

Chart 2 - Comparative table of cost, transport load and average speed - BRT, VLT, MNT.

SUPPORT FOR DECISION MAKING IN COMPLEX SCENARIOS

The presence of a multiplicity of criteria, decision agents and solution alternatives for solving a given problem characterizes a complex scenario in which a choice decision must be made. There are several methods available to assist or support the decision maker or decision makers in problems contextualized in complex scenarios (GOMES et al, 2004; GOMES, 2014; MACHARIS, 2015; YU, 2011).

Criteria

Criterion is a qualified attribute with information given by the Decision Maker (TD) involved in a specific case. For example, the cost attribute can be qualified by a given value or a range of values (GOMES et al, 2004).

In the specific case, the criteria are chosen from the Decision Maker (TD) evaluation axes. From these axes it is possible to compare possible alternatives. There is no formula for choosing criteria. The TD, plus an analyst and other technicians participating in the process of the specific case, must work on the choice, in which some basic rules must be obeyed: select those that interest to the TD; not be redundant; be the minimum necessary that can each one be evaluated independently regarding the chosen set of criteria. Subcriteria are a division of the criterion, made with the objective of reaching down levels that can be quantified. Criteria and sub-criteria are used in a decision problem to analyze alternatives in order to select the best one, separate the good ones from the bad ones, order them in preference level and well describe them (GOMES et al, 2004).

Decision Agents

The Agents involved in a given decision problem are the TD, Analysts and Stakeholders. Stakeholders are defined by Freeman (1984; 2017) as any group of individuals who can affect or can be affected by the achievement of an organization's objectives. In this particular work, the stakeholders are also named as decision agents.

The TD is the individual or group of individuals that make or makes the judgment at the final moment of evaluating the viable alternatives to solve the decision problem. The Analyst is one individual or group of specialists that model the problem and, eventually, make recommendations to the TD to influence its final decision (GOMES et al, 2004).

In specific cases, the Stakeholders can be identified in processes of brainstorming, indications by the specialists, indication of people from entities that acts on the topic under study, selection by the participants on the case or pre-determination of the TD (MORAIS, 2011).

Bryson (2011) describes a process with five steps and twelve techniques dedicated to the identification, data collection and analysis of information or opinions of the Stakeholders. The first step deals with evaluation planning and uses the techniques of listing candidates, analyzing their profiles and interests in participating in the evaluation program. The second deals about how the candidates will be participating on the process and how it will be the relationship between evaluator and evaluated. The third step deals with data collection. In the fourth step the data collected is analyzed. And, in the last phase, the interviewer evaluates the recommendations and incorporates them into the project strategy.

As examples of candidates for Stakeholders in case studies related to the theme of transport, the following are mentioned: CREA (Regional Council of Engineering and Architecture); DETRAN (Municipal Department of Transport); academic community; consulting companies and transportation service providers; systems and equipment manufacturers; local community leaders; representatives of the Ministry of Transport; bus operators; train and subway operators; politicians; representatives of the State Transport Department; representatives of unions linked to transport and users (author, adapted from

MORAIS, 2011).

There are cases in which the preferences given to the criteria are given by different classes of Agents that represent the public Authority, operators, users, the community neighboring the project, suppliers of equipment and services, consultants, suppliers of equipment and services, consultants etc. The researched sources recommend that the final synthesis of judgment be made using the geometric mean of the preferences attributed by all these classes of agents (GOMES, 2004).

Decision-Making Support Methods

Decision cases can be classified as discrete, when the alternatives for solving the problem are finite in number, and continuous, when they are in large number or tend to an infinite number (GOMES et al, 2004).

The multicriteria decision support (AMD) methods most representative of the first class are the AHP (Analytic Hierarchy Process) and the Electre Multiattribute Utility ones. Methods for contexts with lots of alternatives are basically mathematical programming methods. The AHP Multiattribute Utility method is from the American school which, over time, had more than one version: Classic AHP; Multiplicative AHP; AHP BG; AHP ANP and FUSSY AHP. The French school developed the families of discrete methods named Electre (Elimination Et Choix Traduisant la Réalité) and Prométhée (Preference Ranking Organization Method for Enrichment Evaluations). The first one has the versions Electre, Electre I, Electre II, Electre III, Electre IV and Electre TRI. And the second the set of versions Prométhée, Prométhée I, Prométhée II and Prométhée V (BALALI, 2014; BARAN, 2014; GOMES et al, 2004; MACHARIS, 2015; SOLTANI, 2015; VELASQUES, 2013; YU, 2011).

Among the hybrids - a third set - are the Topsis methods (Technique for Order of Preference by Similarity to Ideal Solution) and Todim (Multi-Criteria Interactive Decision Making). Other methods are known as MART, GP, WCL, OWA, SAW, DEA, DEMATEL, HANP, RBMCA, MAUT (Multiple Attribute Value Theory), Regime, MAMCA (Methodology for multi-stakeholder, multi-criteria analysis), UTA and Fuzzy SET (GOMES et al, 2004; MACHARIS, 2015; SOLTANI, 2015; VELASQUES, 2013). Although there are different methods of multicriteria support for decision making, they have in common the steps that must be followed: definition of the decision problem; identification of viable alternatives; selection of evaluation criteria; elaboration of a decision matrix that compares preferences to criteria and the performance of alternatives; prioritization of alternatives towards meeting the criteria; and decision making (TERRADOS, 2010).

Follow a brief description of the Classic AHP method, used in this work as a guide for assembling the model used in the case study.

AHP Method

The AHP method was initially developed in the 1970s to solve a military resource planning problem. It was then used to study future alternatives for Sudan, assessing priorities and a plan of investments. Applications were developed in the areas of energy, feasibility studies of new technologies, alternatives to purchase cars, evaluation of job opportunities, selection of schools, among others (SAATY, 1991).

Over time, it has been used as a tool to support decision-making in complex scenarios in different fields, such as: management decisions; selection of engineering processes; selection of manufacturing processes; product selection (vehicles, telecommunications, information technology, etc.); selection of logistics strategies such as choosing alternative routes in transport systems and selection of employees by human resources teams (SAATY, 2008).

In the transport sector, the AHP method has applications that cover evaluations of public policies, technologies, infrastructure, choice of locations for installations, allocation of resources and choice of modes, among others. A study shows that among 276 publications on multi-criteria analysis carried out in the transport sector (in the categories of passenger, cargo, technology and general transport and subcategories of air, water, rail, bicycles, infrastructure, logistics, technology and others), 33 % of them used the AHP method (MACHARIS, 2015; YU, 2011; SAATY, 2008).

The set of techniques of the method makes it possible to order in order of priority the list of candidate alternatives to solve the problem. It can deal with objective and/or subjective considerations, quantitative and/or qualitative information and weights generated from linguistic and numerical assessments. The basic premise is that all alternative candidates for the final choice must satisfy a desirable set of criteria and the decision problem boils down to choosing which one best satisfies the set of criteria. Better satisfying the set of criteria means better meeting the preferences of multiple stakeholders involved in the selection process and have better technical and operational performance (MACHARIS, 2015; SAATY, 1991; SAAYY, 2008; YU, 2011).

Architecture

The macrostructure of the decision method is shown in Figure 13. The first block of the figure represents the decision problem and, just below, two branches follow. In the first are the criteria and sub-criteria, the decision agents' preferences for the criteria and sub-criteria, the pairwise comparison matrices and the criteria and sub-criteria priority vectors. In the second branches are the alternatives, the performances of the alternatives that are raised by the analysts, the pairwise comparison matrices and the vector of alternative priorities. These two branches intertwine with the processing of criteria and alternatives priority vectors, resulting in the Global Priority Index (GI). It is through the analysis of the IG that the TD decides on the best alternative to solve its decision problem.

To calculate the GI, the method starts with the pairwise comparison between the preferences for the criteria, continues with the pairwise comparison between the performances of the alternatives in relation to the same criteria and ends with the processing of the two comparisons with a mathematical model of function additive linear value that calculates the GI.

There is a set of axioms that must be considered valid by the decision maker, decision agents and analysts and they concern the order of preferences between the criteria and the completeness of the hierarchical structure shown in Figure 12 (GOMES et al, 2004; SAATY, 1991, SAATY, 2008).

- Criteria, transitivity of preference: if ***a*** is preferable to ***b*** and ***b*** is preferable to ***c***, then ***a*** is preferable to ***c***;
- Criteria, transitivity of indifference: if ***a*** is indifferent to ***b*** and ***b*** is indifferent to ***c***, then ***a*** is

Indifferent to ***c***.

- Criteria, reciprocity: if ***a*** is **x** times more preferred than ***b***, then ***b*** is **1/x** times more preferred than ***a***;
- Criteria, independence: the criteria must be mutually independent in relation to the preferences of decision-makers;
- Criteria, scale of preferences: the preferences of decision makers are assigned with a numerical scale in which each level has its importance described textually;
- Hierarchical structure of the concrete case: the hierarchical structure (problem, criteria, sub-criteria, alternatives) assembled in levels must be complete.

The steps that must be followed to arrive at the classification of alternatives in order of preference (SAATY, 2008; SAATY, 1991; SAATY, 2011) are:

- Clearly define the problem and the objective sought;
- Define decision-makers;
- Define the applicable criteria, sub-criteria and alternatives;
- Assemble the hierarchical decision structure (Figure 14);
- Survey decision agents' preferences by criteria and sub-criteria, together with the decision Agents;
- Raise the scores of the alternatives in compliance with the criteria and subcrite-

ria using specialists and/or consulting the applicable bibliography;

- Calculate the priority vectors of the criteria, sub-criteria and alternatives with the pairwise comparison matrices;
- Evaluate the consistency of the calculations according to the AHP method technique;
- Determining the final preference order of the alternatives, combining the priority vectors of criteria, sub-criteria and alternatives;
- Analyze the sensitivity of the order of preference of alternatives as per changes in the judgments made by decision-makers. The Expert Choice (GOMES, 2004) is a software tool available for the AHP method (not used in this research) that performs dynamic sensitivity analysis.
-

Hierarchical structure of the decision model

Figure 14 shows the hierarchical organization proposed by the AHP method. At the top of the hierarchy (Level 1) the description and objective of the problem should be placed, with the relevant criteria (Level 2) and subcriteria (Level 3) being listed below. Finally, alternatives (Level 4) capable of solving the problem are allocated. If necessary, the sub-criteria can be subdivided into lower levels, until the hierarchy characterizes all the levels necessary to solve the problem.

Pair-wise comparison matrix

The pairwise comparison of the decision factors (criteria, subcriteria and performance of the alternatives) is done with the so-called comparison matrices. Two classes of matrices must be set up, one to compare the criteria and the other to compare the performances of the alternatives. Then, these two classes are combined to obtain the final solution that lists the alternatives, placing first the one that best meets the decision problem.

The quantification of the relative importance among the relevant criteria of the problem is done by assigning them degrees of importance according to the Fundamental Scale of Values (Table 4) developed by Saaty (1991).

Figure 13 shows the macrostructure of the AHP method.

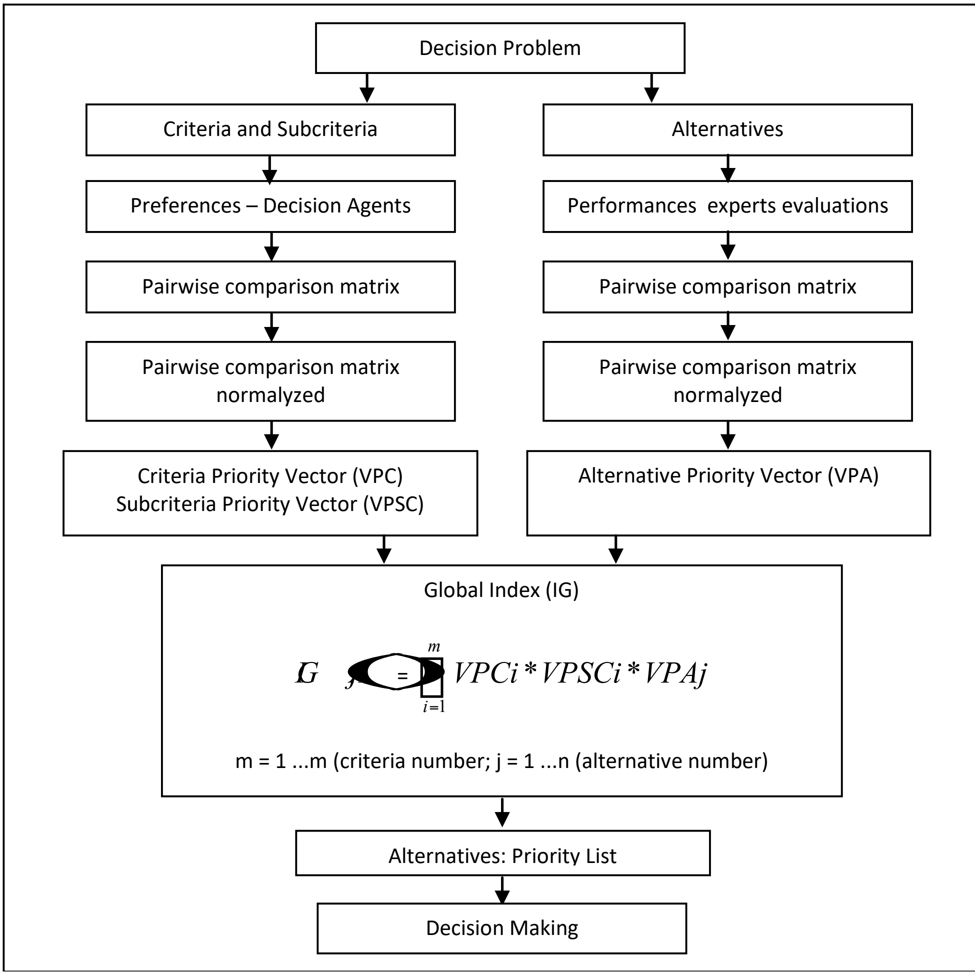

Figure 13 - Macrostructure of the AHP decision method.
Source: Prepared by the author.

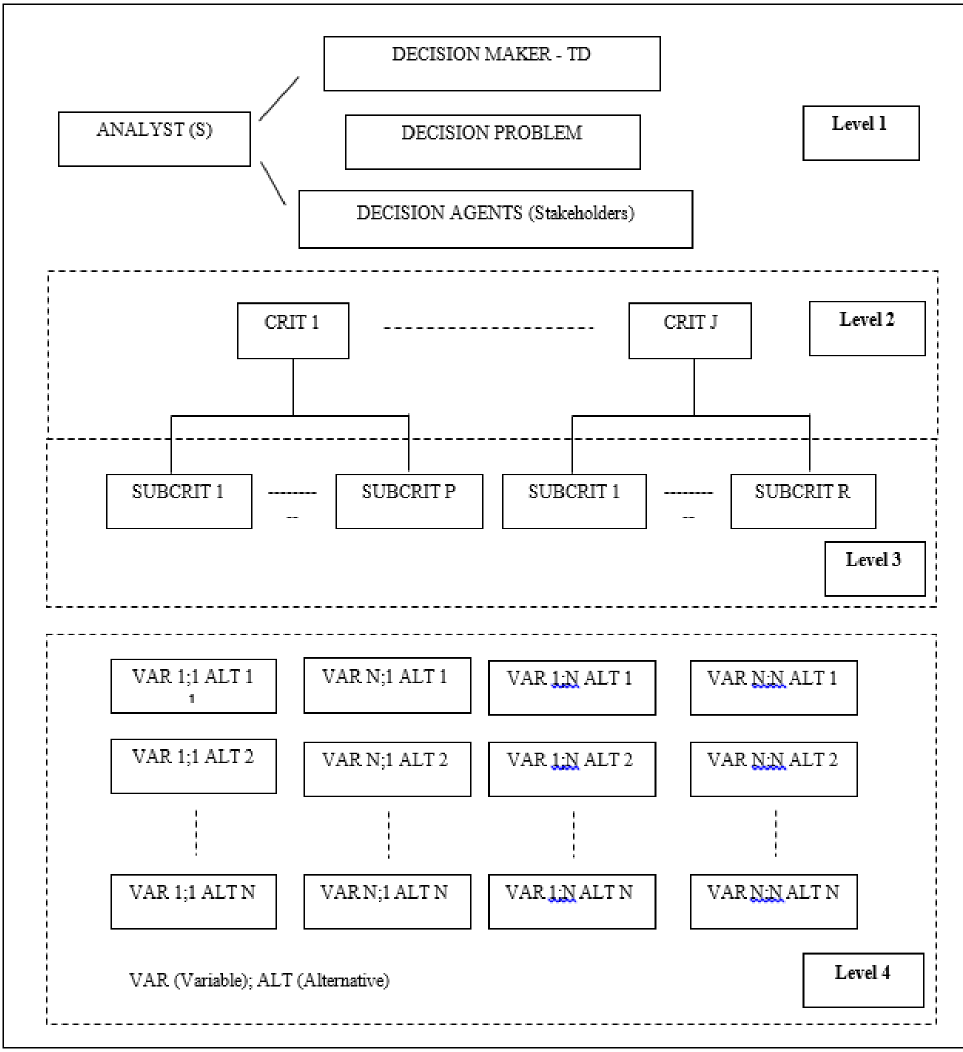

Figure 14 - Hierarchical structure of the AHP decision method.
Source: Prepared by the author; based on SAATY, 1991.

Fundamental Value Scale		
Scale	Importance of Criterion A over B	Importance of Criterion B over A (Reciprocity of Importance)
1	Equal	1/1
2	Weak or Little	½
3	Moderate	1/3
4	Moderate (+)	¼
5	Strong	1/5
6	Strong (+)	1/6

7	Very Strong	1/7
8	Very, Very Strong	1/8
9	Extreme	1/9

Table 4 - Fundamental Value Scale.
Source: SAATY, 1991; data adapted by the author.

AHP Method - Application Example

Here is an example of application for the Classic AHP method described step by step: the pairwise comparison of the criteria; the calculation of the Criteria Priority Vector (VPC); the pairwise comparison of the performances of the alternatives; calculation of the Priority Vector of Alternatives; the finalization of the problem, combining the two vectors and listing the alternatives in order of score.

The problem is to list the alternatives of collective urban transport modes BRT, LRT and MNT (author's note: the acronym MNT is used in the example to designate the Monorail mode) in order of preference.

The decision-making agent (TD) defined three evaluation criteria: average investment of cost per km (CK) of track in R$/km; average energy intensity (consumption) of vehicles (IEV) in Mj/p-km and average installation time (TI) of 10 km of track in years.

The hierarchical structure of the problem is shown in Figure 15.

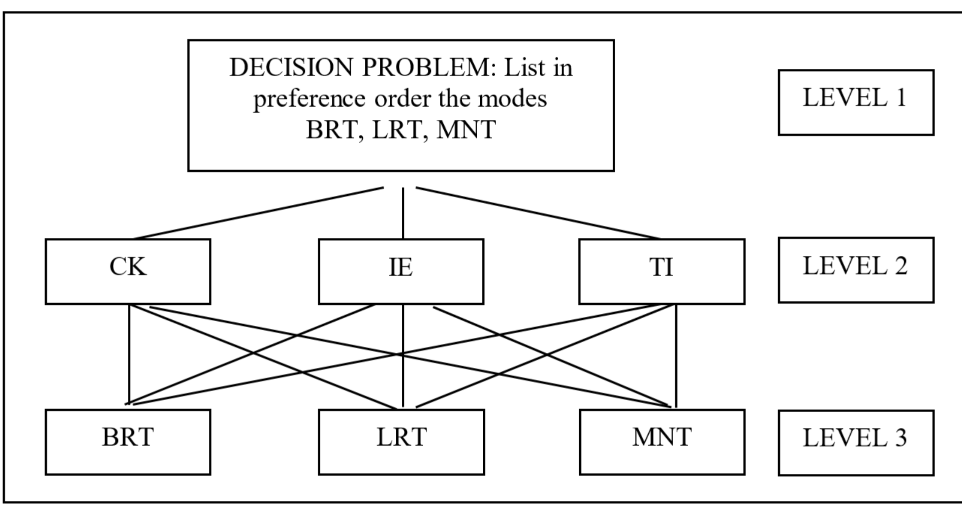

Figure 15 - Hierarchical structure of the decision problem - Example.
Source: Prepared by the author.

The decision makers involved in the case attributed their preferences to the three criteria using the Fundamental Scale indices: CK = 3; IEV = 7; IT = 5.

Pairwise comparison of decision makers' preferences for criteria

Table 5 shows the pairwise comparison of the criteria.

CRITERIA	CK	IEV	TI
CK	1	1/7	1/5
IEV	7	1	7
TI	5	1/7	1

Table 5 - Criteria pairwise comparison matrix.
Source: Prepared by the author.

The next step is to calculate the Criterion Priority Vector (VPC) which is the vector (Column Matrix) calculated by the average of the sum of the lines of the normalized Comparison Matrix (Table 6). The same Table also shows the Consistency Vector (VC). The closer the VC lines are to the matrix degree – 3, in this case – the greater the consistency attributed by decision-makers to the preferences for the criteria.

CRITÉRIO	CK	IEV	TI	VPC	VC
CK	0,0769	0,1111	0,0244	0,0708	3,0408
IEV	0,5385	0,7778	0,8537	0,7233	3,6779
TI	0,3846	0,1111	0,1220	0,2059	3,2214

Table 6 - Normalized pairwise comparison matrix of the criteria.
Source: Prepared by the author.

The VPC vector is composed of lines that have approximate values and is considered consistent through a computational resource called Consistency Ratio (RC). Two types of inconsistency are considered by the AHP Method: one of judgment and another due to the criteria and alternatives adopted. The first is due to the proportionalities that the decision-maker attributes to the criteria. For example, he may assign weak or little importance – 2 – to three criteria of the same hierarchical level because he cannot discriminate the existing importance between them. In another example, if importance 2 was assigned to a criterion ***A*** over another ***B*** and importance 3 to ***B*** over ***C***, it is to be expected that ***A*** have, over ***C***, the importance 6 (2*3). However, if the evaluator assigned importance 4, or 5, or 6, or 7, then there is inconsistency in the judgment matrix. The Consistency Ratio will be zero if there is no inconsistency. But the inconsistency is acceptable for values below the critical value of 0.10. If RC is greater than 0.10, preference assignments must be reviewed (GOMES, 2004; MU, 2017; SAATY, 1991).

The Consistency Ratio (RC) is given by the coefficient between the Consistency Index (IC) and the Random Consistency Index (RI) shown in Table 7. The IC, in turn, is a function of the number of criteria and a coefficient called Principal Eigenvalue (λmax).

The coefficient λmax is a scalar value defined by the average of the component lines of the Consistency Vector - VC). The VC vector is obtained by multiplying the Eigenvector of the Comparison Matrix (original matrix, prior to normalization) with the VPC of the normalized Comparison Matrix. In this example λmax is 3.313.

Here is the complete expression that shows the RC calculation (Equation 25):

- AHP Process – Calculation of the Consistency Ratio (RC).

$$RC = IC / RI = [(\lambda max - n) / (n-1)] / RI \qquad (25)$$

"n" is the order of the Comparison Matrix (n = 3 in this example).

The IR (Table 7) is a random index calculated by Saaty (1991) for Comparison Matrices of orders between 1 and 10. In this example, which has a matrix of order 3, IR = 0,58.

N	1	2	3	4	5	6	7	8	9	10
IR	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,46	1,49

Table 7 - AHP Process - Random Index (IR).
Source: SAATY, 1991.

The calculation of the CR of this example is done by applying Equation 26:

- AHP Process – Application Example – RC Calculation.

$$RC = [3.13 - 3) / 2] / 0.58 = 0.27 = 0.27 / 100\% = 0.0027\% \qquad (26)$$

Therefore, the RC is <0.10%, which indicates that the Criterion Priority Vector is consistent.

Another fact that also affects the RC is the eventual violation of the principle of transitivity. If this occurs, the importance relationship between the criteria must be reviewed (SAATY, 1991).

Pairwise comparison of alternative performances

The same sequence, made for the criteria, is repeated in the evaluation of the relative performances of the viable alternatives to solve the decision problem: setting up the pairwise comparison; normalization and calculation and consistency analysis of the priority vector of alternatives (VPA). As the problem has three alternatives, each of them has to have their performance compared against each of the criteria.

Table 8 shows the performance of the alternatives, surveyed by the decision problem analyst (author, in this case) for the variables selected for this project.

ALTERNATIVE \ PERFORMANCE	CS (R$/106/ km)	1/CS (106/ km/ R$)	IEV (Mj/p-km)	1/IEV = EEV (p-km/ Mj)	TI (Years for 10km)	1/TI (10km /year)
BRT	25	4,0000	0,270	3,703	1,5	0,6667
VLT	70	1,4286	0,216	4,629	4,0	0,2500
MNT	85	1,1765	0,190	5,2632	2,0	0,5000

Table 8 - Performances of the BRT, VLT and MNT modes.
Source: Prepared by the author.

CS = Cost/km; Cost Efficiency = 1/CS; IEV = Vehicle Energy Intensity; 1/IEV = EEV = Vehicle Energy Efficiency; TI = Installation Time and 1/TI = Installation Efficiency.

It is up to the decision maker to make the final choice of the alternative at his/her discretion, prioritizing the one with the lowest cost, or the highest energy efficiency, or the shortest installation time. They can, by performing a sensitivity analysis, assess the interrelationship between the VPC and the performance of the alternatives.

The Comparison Matrix of the cost performances of the alternatives is shown in Table 9. And the same matrix, normalized, in Table 10, also shows the cost priority (VPCO) and consistency (VC) vectors.

FACTOR	EFCS BRT	EFCS LRT	EFCS MNT
EFCS BRT	1,0000	4,0000	4,0000
EFCS VLT	0,2500	1,0000	1,4286
EFCS MNT	0,2500	0,7000	1,0000

Table 9 - Cost performance comparison Matrix.
Source: Prepared by the author.

FACTOR	EFCS BRT	EFCS LRT	EFCS MNT	VPECS	VC
EFCS BRT	0,6667	0,7018	0,6222	0,6635	3,0282
EFCS VLT	0,1667	0,1754	0,2222	0,1881	3,0084
EFCS MNT	0,1667	0,1228	0,1556	0,1483	3,0059

Table 10 - Cost performance comparison matrix, normalized.
Source: Prepared by the author.

Calculated Consistency Ratio: 0.001%, <0.10%.

The Comparison Matrix of energy efficiency performances of vehicles is shown in Table 11. And the normalized matrix in Table 12, which also shows the priority vectors of priority of energy efficiency and consistency (VPEE) and consistency (VC).

FACTOR	EEV BRT	EEV LRT	EEV MNT
EEV BRT	1,0000	0,2160	0,1200
EEV VLT	4,6290	1,0000	0,1900
EEV MNT	8,3330	5,2632	1,0000

Table 11 - Matrix for comparing the energy efficiency performances of vehicles.
Source: Prepared by the author.

FACTOR	EEV BRT	EEV LRT	EEV MNT	VPEEV	VC
EEV BRT	0,0716	0,0333	0,0916	0,0655	3,0197
FACTOR	EEV BRT	EEV LRT	EEV MNT	VPEEV	VC
EEV VLT	0,3315	0,1543	0,1450	0,2103	3,0965
EEV MNT	0,5968	0,8123	0,7634	0,7242	3,2825

Table 12 - Matrix for comparing the energy efficiency performances of vehicles, normalized.
Source: Prepared by the author.

Calculated Consistency Ratio: 0.001%, <0.10%.

The Comparison Matrix of the installation time (TI) performance of the alternatives is shown in Table 13. And the normalized matrix in Table 14, with the vector columns, installation time priority and consistency.

FACTOR	EFTI BRT	EFTI LRT	EFTI MNT
EFTI BRT	1,0000	6,6670	6,6670
EFTI VLT	0,1500	1,0000	0,2000
EFTI MNT	0,1500	5,0000	1,0000

Table 13 - Installation time performance comparison matrix.
Source: Prepared by the author.

FACTOR	EFTI BRT	EFTI LRT	EFTI MNT	VPEFTI	VC
EFTI BRT	0,7692	0,5263	0,8475	0,7143	3,6660
EFTI VLT	0,1154	0,0789	0,0254	0,0732	3,0427
EFTI MNT	0,1154	0,3947	0,1271	0,2124	3,2287

Table 14 - Installation time performance comparison matrix, normalized.
Source: Prepared by the author.

Calculated Consistency Ratio: 0.003%, <0.10%.

Synthesis

Then, a synthesis is made between the preferences attributed by the decision agents

(Stakeholders) to the criteria and scores calculated for the performance of each alternative by the project Analyst. This synthesis results in the Global Index (GI) for each alternative and, based on it, the ranking of the alternatives in order of priority. The GI is calculated by the sum of the multiplications between the priority vectors of criteria – and of sub-criteria when applicable – and priority of alternatives.

Equation 27 (SAATY, 1991) shows the additive function that generalizes the calculation of the project's GI. In the equation, ***m*** is the number of criteria (three in this example) and ***j*** the number of alternatives (also three in this example). The weights or preferences of decision makers for the criteria are represented by the letter ***w*** and the performance of each alternative by ***vj***.

- AHP Process - Global Index Calculation:

$$IG\ (Aj) = \sum_{i=1}^{m} wi(Ci) * vj(Aj) \qquad (27)$$

Equations 28, 29 and 30 show the calculations of the GI(s) of the three alternatives in this specific case.

- AHP Process - Global BRT Index – Example.

IGBRT = 0.0708x0.6635+0.7233x0.0655+0.2059*0.7143 = 0.2415 (28)

- AHP Process - Global LRT Index – Example.

IGVLT = 0.0708x0.1881+0.7233x0.2103+0.2059*0.0732 = 0.1805 (29)

- AHP Process - Global MNT Index – Example.

IGBRT = 0.0708x0.1483+0.7233x0.7242+0.2059*0.2124 = 0.5780 (30)

In this example, the order of priority indicates the LRT first, followed by the MNT and the BRT (Table 15; Figure 16).

The calculated GI(s) show the priority order of the modals: MNT (1), BRT (2) and LRT (3).

Importance (Preferece) given by the decision agents to the Criteria (VPC)		Mode	Performance of the mode on each Criteria			IG of each Alternative	Final order of Preference
			Efficience Cost:km/R$	Energetic Efficience: p-km/Mj	Efficience of Average time for installation: 10 km/year		
Cost	0,0708	BRT	0,6635	0,0655	0,7143	0,2415	2
Energetic Efficience	0,7233	LRT	0,1881	0,2103	0,0732	0,1805	3
Installation Time	0,2059	**MNT**	0,1483	0,7242	0,2124	0,5780	1

Table 15 - Global Index and Final Priority Order of Alternatives - Example.
Source: Prepared by the author.

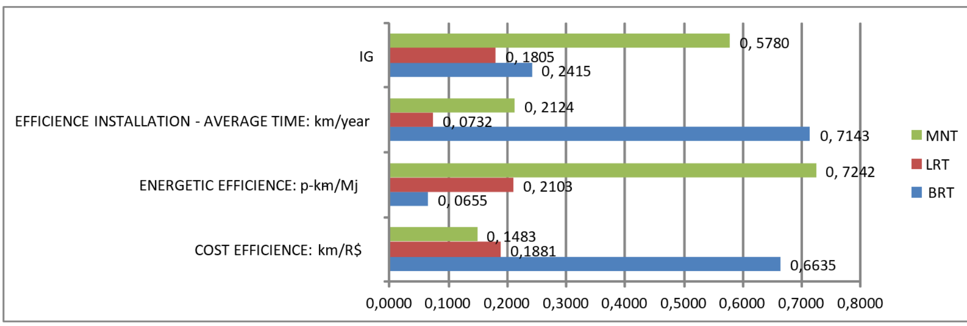

Figure 16 - Global Index and Final Order of Preference of Alternatives - Example.
Source: Prepared by the author.

Sensitivity analysis

Table 15 can serve as a basis for carrying out sensitivity analyses, changing the preferences given by the stakeholders to the criteria and checking what happens with the order of priority of the alternatives.

To exemplify this type of analysis, Table 16 and Figure 17 show what happens when equal preferences are assigned to all criteria (Scenario 1). And Table 17 and Figure 18 show the effect of changing the weights between the cost and energy efficiency criteria between the BRT and the LRT (Scenario 2).

In these two scenarios the order of priority changes to BRT (1), MNT (2) and LRT (3). Note that, in Scenario 2, the GI(s) of the LRT and the MNT are very close (0.1660 and 0.2023) while the BRT is well above (0.6317).

Importance (Preferences) given by the Stakeholders to the Criteria (VPC)		Mode	Performance of the mode on each Criteria			IG of each Alternative	Final order of Preference
			Efficience Cost: km/ R$	Energetic Efficience: p-km/Mj	Efficience of Average time for installation: 10 km/year		
Cost	0,3333	**BRT**	0,6635	0,0655	0,7143	0,4811	1
Energetic Efficience	0,3333	LRT	0,1881	0,2103	0,0732	0,1572	3
Installation Time	0,3333	MNT	0,1483	0,7242	0,2124	0,3616	2

Table 16 - Global Index and Final Order of Preference of Alternatives - Example[8].
Source: Prepared by the author.

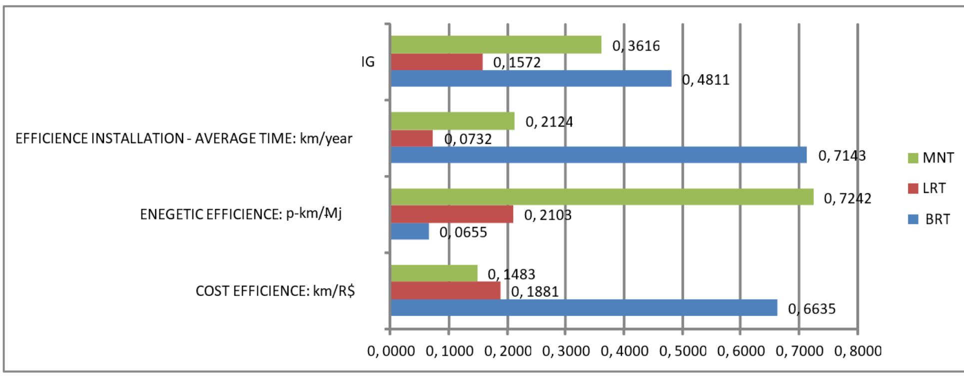

Figure 17 - Global Index and Final Order of Preference of Alternatives - Example[9].
Source: Prepared by the author.

Importance (Preferences) given by the Stakeholders to the Criteria (VPC)		Mode	Performance of the mode on each Criteria			IG of each Alternative	Final order of Preference
			Efficience Cost: km/ R$	Energetic Efficience: p-km/Mj	Efficience of Average time for installation: 10 km/year		
Cost	0,7233	**BRT**	0,0655	0,7143	0,7261	0,6317	1
Energetic Efficience	0,0708	LRT	0,2103	0,0732	0,0551	0,1660	3
Installation Time	0,2059	MNT	0,7242	0,2124	0,2188	0,2023	2

Table 17 - Global Index and Final Order of Preference of Alternatives - Example[10].
Source: Prepared by the author.

8. Scenario 1 – All criteria with identical preferences.
9. Scenario 1 – All criteria with identical preferences.
10. Scenario 2 - Cost and Energy Efficiency Criteria with inverted preferences.

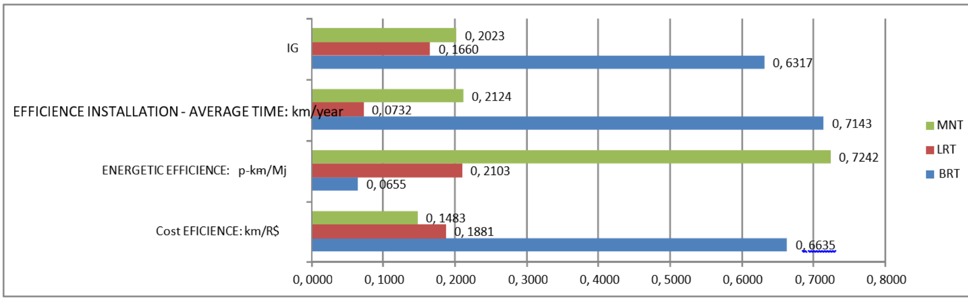

Figure 18 - Global Index and Final Order of Preference of Alternatives - Example.
Source: Prepared by the author.

Applications of the AHP Method in Collective Urban Transport

The AHP method has applications carried out in the transport sector in the analysis of different problems: evaluation of transport policies; assessment of advanced technologies; mode comparison; infrastructure assessment such, for instances, assessment of route options and assessment of locations for intermodal stations (MACHARIS et al, 2009).

There are many examples of application of the AHP method in the public urban transport sector. Some of them are mentioned, without the intention of exhausting them, but with the aim of exemplifying types of problems and results obtained with the application of the method. Chart 3 exemplifies four types of problems in the area of collective urban transport: comparison of performance between modes; performance comparison between operators (Authorities); prioritization of actions to improve mobility and prioritization of routes.

CASE TITLE	DECISION PROBLEM	RESULT	REFERENCE
Comparison of systems performance - medium capacity public transport via AHP - BRT x LRT - Study in Rio de Janeiro.	**Compare performances of operating system for BRT and LRT** on the TransOeste line in Rio de Janeiro. Criteria: energy efficiency, trip quality, operating cost.	Within the criteria adopted, the BRT exceeded at the LRT.	OLIVEIRA, G.T., 2016
Comparison of conventional and modern public transport systems.	**Compare the performance of PRT (Personal Rapid Transit) with those of traditional modes:** Metro, LRT, Monorail and Tramway. Criteria: Social, Technical and Economic.	The study concluded that PRT is comparable to traditional mode because also meets to the social, technical and economic requirements.	MORADI, M. et al.al, 2014.

A multi-criteria decisionmodel for urban mass transit system.	**Compare the performance of the BRT and LRT modes. Criteria:** 13 subcriteria grouped into 4 groups: Benefits, Opportunities, Costs and Risks.	The model showed preference for BRT, showing the prevalence of the mode currently in operation (in Istanbul).	TOPEU, YI; ONAR, SC, 2011.
Performance analysis of public transport operators in Tunisia using AHP method.	**Compare the performances of different operators** working under similar conditions. Criteria adopted: Cost, Efficiency, Effectiveness and Quality of Service.	The study concluded that: - The Public Authority must provide subsidies to the public transportation, supporting investments for operating and maintenance costs; - And the operators of public transportation systems should increase their productivity.	BOUJELBENE, Y.; DERBEL, A.,2015
Multi-Criteria analysis to support mobility management at a university campus.	**Identify the preference structure aiming to improve mobility on campus**. Criteria: car parking area; encouraging car-sharing; encouraging pedestrian movement.	The preferences found, in hierarchical order, were: increase the area of parking lot; encourage sharing of vehicles (pool), encourage public transport and prioritize circulation of pedestrians.	LONGO, G. et. al., 2015.
Public Transportation Decision-Making: A Case Analysis of the Memphis Light Rail Corridor and Route Selection with Analytic Hierarchy Process	**Among two possible routes (CA and CB), select the best one** for installing the LRT mode. Criteria: Mobility, TOD (Transit Oriented Development) and Cost.	The best route scored was the alternative CB.	BANAI, R., 2006.

Chart 3 - Examples of application of the AHP method in the transport sector.
Source: Prepared by the author.

FUNCTIONAL UNIT

Functional unit is a concept defined in the field of Life Cycle Analysis (LCA). Although the objective of this study is not to carry out an LCA to assess and compare the environmental impacts of the three public transport alternatives under analysis, the Functional Unit is used here to define the common base of functionalities that the BRT, LRT and MON must meet. From this common base, the three systems are designed and configured according to their own characteristics and, thus, homogenized so that they can be compared.

The concept of Functional Unit is defined in the ABNT NBR ISO 14040/14044 Standards (2009, p. 3) as the quantified performance of a product system to be used as a reference unit. The Standard defines product as any good or any service. And product system as a set of elementary processes, with elementary and product flows, performing one or more defined functions and that models the life cycle of a product. The same standard further defines elementary flow as,

> "(...) material or energy taken from the environment and which enters the system under study without undergoing prior transformation by human interference, or material that is released into the environment by the system under study without undergoing subsequent transformation by human interference."

An example of application of the Functional Unit concept is the evaluation of a system whose functional unit is the drying process for 200 people hands. This functional unit can be serviced by a paper towel drying system or a hot air drying system. The two systems can be compared by quantifying the elementary reference flows of the two systems: amount of paper or energy. For example, ***x*** kg of paper on the first process and consumption of ***y*** kWh of electricity on the second one (CHEHEBE, 2002).

Another example is the case of the functional unit defined by the painting process of $\mathbf{x}^2$ of wall. This functional unit can be serviced by paint cans from supplier A and supplier B. The two suppliers will be able to have the performance of their paint cans compared against the reference flows of paints from the two suppliers: how many cans are needed from A or B for painting **x** m^2 of wall?

The two examples shown have the evidences that, in case of comparisons between systems, they must be functionally equivalent. In the case of the examples cited, in the first of them, both systems lend themselves to drying hands. In the second, both lend themselves to painting walls (Ibidem, 2002).

The functional unit can also be used as the basis for comparing performances in product improvement, before and after their redesign (MANZINI, E.; VEZZOLI, C, 2008).

Bringing these concepts to people transportation systems, a possible functional unit is the number of passengers transported per km. If a particular study in the transport sector focuses on making comparisons across the entire spectrum of people mobilization, it should be considered to do segmented studies for private (individual) transport, or public (collective), by land, or rail, or air, and so on (Ibidem; 2008).

According to Tchertchian (2016), the definition of a functional unit is fundamental in LCA studies and it is also imperative that the product and system options, which must be analyzed, perform the same functionalities in cases of comparisons. He reminds us that great systems are composed of subsystems. When the system is divided, the subsystems can provide greater precision in the results and/or focus on specific areas of interest. A study by the author, who researched scientific papers published by the editors Springer, Taylor

& Francis and Elsevier, between 2003 and 2013, as well as LCA studies in the transport sector concerning the analysis of new technologies, especially in vehicles, indicated that the concept of functional unit that was almost always present in these works was that of "transport of people or objects from point A to point B, located 1,000 km away". The works also noted that, in the case of vehicles, as they are complex systems, studies should consider dividing them into subsystems.

In life cycle analysis of transport systems, the results are calculated by normalizing the functional unit almost always in vehicle per mile traveled in the case of freight transport or in passenger per mile traveled in the case of passenger transport. However, the functional unit can be expressed in any metric that the transportation agency or analyst deems relevant. For example, vehicle-mile-cost unit, or travel time per passenger, passengers per unit of time, etc. If the study's goal is to survey regional vehicle emissions, then one vehicle per mile traveled is adequate. If the goal is to assess emissions associated with travel characteristics, then the passenger per mile traveled metric is more appropriate (CHESTER, 2010).

Dave (2010) used the functional unit of passenger per mile traveled in his study of transport life cycle assessment because it was the most appropriate metric to adequately compare the effects of bus and car emissions. At first glance, buses consume more energy than cars, but with high passenger occupancy and depending on the miles traveled, they are more efficient.

The functional unit defined in a life cycle assessment study carried out in Trondheim, Norway, was one passenger-km transported for an average citizen in terms of transport usage in the city area (BUO, 2015). This functional unit made it possible to compare the environmental performance of different bus routes, despite the differences due to the circulation of different types of vehicles, covering the service over a year. This functional unit also made it possible to compare transport performed by buses and cars (Ibidem; 2015).

From the examples above described, one can conclude that the functional unit is fundamental to compare systems that perform similar functions. Also, it is established case by case, according to the characteristics of the study. The functional unit of the problem must be described in a clear and detailed way, with elements that make it possible to measure the performance of the system under analysis or the performance of the systems in comparison. Once defined, the functional unit is the base that makes possible the criteria to be set and analyzed towards comparing alternatives that meet such set.

The proposal to use a functional unit in this work has as assumption to define, from this concept, the basis to be used to compare modes that perform or that may perform, provided that the limits of functionality are established. Once the functional unit is established, what are compared are the performances of viable alternatives for the case in relation to the analysis of the selected set of criteria.

For example, if the functional unit is passengers transported per unit of time and the specific case defines how many passengers are transported and for how long, then all the alternative solutions can be compared, for example, with respect to the criteria of: cost; economic and financial viability; energy efficiency; trip quality; and environmental impacts.

The characterization of the concept of Functional Unit finishes this bibliographic summary. The work continues with the description of the model adopted to carry out the specific case study of this study.

METHOD

NATURE OF RESEARCH

This research has an exploratory nature, since it establishes criteria, methods; bibliographic research, field research and interviews with agents involved with the research topic were established, in addition to a case study (GERHARDT, 2009; YIN, 2014). The field research took place during visits and meetings with technicians from the BRT Expresso Tiradentes systems in São Paulo, the LRT in Santos and the MNT of Line 15 of the São Paulo Metro. Such actions served as a basis for setting the hypotheses and achieving the objective of the work. The case study used the decision-making support model.

MACROSTRUCTURE OF THE DECISION SUPPORT MODEL

The proposed model to support decision making, in the selection of modes for collective urban transport, is composed of four fundamental modules characterized by the set of criteria and sub-criteria, the preferences of the stakeholders, the performances of the alternatives and the math module that processes the preference and performance data. Figure 19 shows the model's macrostructure and the interconnections between the four modules. The drawing also shows: the blocks on which acts the stakeholders (also knows as Decision Agents), the Analyst (or Analysts) and the Decision Maker (or group of Decision Makers) (TD); in which blocks are used the information referring to the functional unit; and those information contained in Annexes I (Procedure - Preferences of Decision Agents), II (Tables - Preferences of Decision Agents) and III (Calculation Memorial - Performance of BRT Alternatives, LRT and MNT).

Figure 19 was constructed from the following narrative: a decision maker TD (or group) has a concrete choice problem for which there is more than one alternative solution. The TD hires the support of an expert (or group) (Analyst) who has technical knowledge about the decision problem and about the viable alternatives, to help him to form an opinion about which one would be the best to solve his (TD) concrete problem. A set of criteria (and sub-criteria) is assembled by the Analyst, discussed with the TD and submitted to the stakeholders to score them according to their preferences on a scale from 1 to 9. The Analyst studies the viable alternatives and scores their performance on the same scale and against the same set of criteria. Scores are processed into a mathematical model that synthesizes preferences (of Stakeholders) and performances (of Alternatives) into a global index (GI) for each alternative.

As the narrative has a general nature, the model must be configured to deal with specific concrete cases. The case study model of this research is configured with a set of criteria and sub-criteria that covers the economic, social and environmental axes of sustainability, the preferences for the set of criteria, collected in an opinion survey (conducted by the author) obtained ou of 138 samples realized in the region of the city of São Paulo, Brazil, and the performances of the three modes under analysis, obtained (by the author) in the consulted bibliography and in field observations. The quantitative data originating from this configuration make up the vectors VPC, VPSC and VPA. These three vectors are processed through an additive function, which generates the GI index for each viable alternative. The general model proposed can be used on specific cases that deal with comparisons and selection of collective urban transportation modes, once observed the following considerations:

- Set of criteria and sub-criteria: the proposed set is comprehensive in nature with respect to sustainability studies, but its scope must be assessed on a case-by-case basis;
- Preferences of Decision Makers: must be reviewed, if the case study is carried out outside the São Paulo city region; for applications outside this region, the suggestion is that a new opinion poll be conducted;
- Alternative performance indices: they are specific to the alternatives in the concrete case;
- Mathematical module of the AHP method: all criteria preference matrices and alternative performances must be configured for each specific case;
- Functional Unit: is specific to each case study.

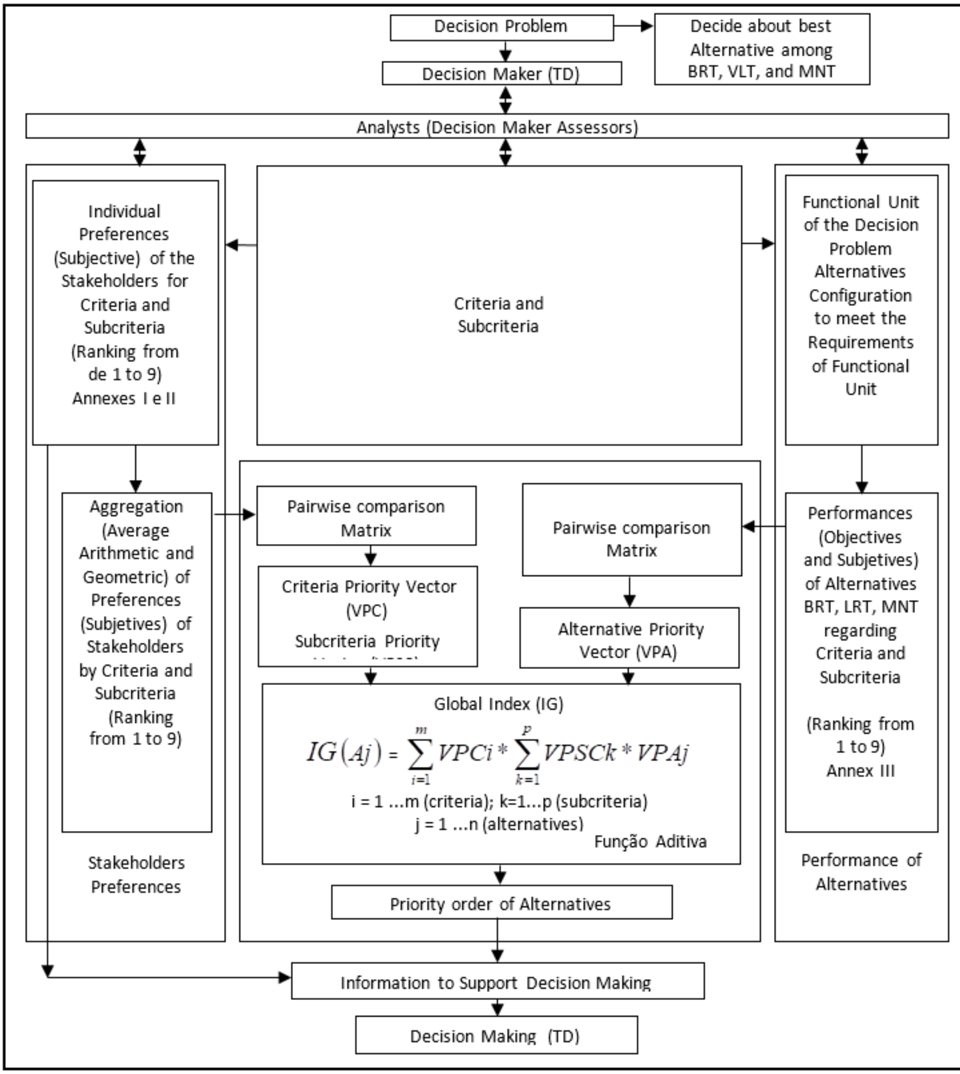

Figure 19 – Macro-structure of the model to support the Decision Maker.
Source: Prepared by the author.

DATA SURVEY OF CASE STUDY

The data are following presented.

Preferences of Decision Agents

The decision-makers' preferences for the criteria and sub-criteria were obtained using a form (Annex I) and are recorded in Annex II.

Performance of Alternatives

The performances of the alternatives were obtained from the bibliographic sources and electronic addresses indicated in lines 2, 3 and 4 of Chart 1 and recorded in Annex III. Some performances were estimated in calculations made by the author, based on information from the manufacturers of the systems and also via information collected in field visits.

CASE STUDY

The case study compares the performance of the BRT, LRT and MNT modes in terms of meeting the operational and functional requirements of the section between Vila Prudente (VPM) and São Mateus (SMT) stations on Line 15 Silver of the São Paulo Metro. The modal in current operation on this Line is the MNT.

Execution Procedure

The comparison process had two major steps. In the first, the characterization of the functional unit was made. It delimits the boundaries of the study and serves as a reference to assembly the functional structure of each of the three modes in comparison. In the next step, the proposed model was applied.

Functional Unit Definition

The functional unit defined for the case study is passengers transported per day on the VPM to SMT stretch of Line 15. This transport corridor was selected as it is very suitable for this job for reasons that it was initially planned by São Paulo town hall technicians to receive a BRT-type system and, later, under the management of the São Paulo Metro personnel, the modal for this corridor was redefined to be the MNT. The BRT modal would extend to Cidade Tiradentes the branch of the Expresso Tiradentes that currently connects Park Dom Pedro II to the neighborhood of Vila Prudente. Part of this system, in operation since 2007, was built with an exclusive lane on a raised concrete deck, and part at street level. The extension to Cidade Tiradentes would be all level with exclusive tracks.

However, the assessment made by the São Paulo Metro technicians, when this company took over the execution of this extension in 2009, indicated that the modal to be installed would need to be totally segregated. This, in order to obtain a minimum average travel speed of 25 km/h, which would require the mitigation of 110 interferences (level crossings in the road system) existing between the VPM and SMT stations, possible to be done with a MNT system. In addition to these 110 interferences, there are 70 others between the SMT station and the future Hospital Cidade Tiradentes (HCT) station, a section that is planned to complement the total length of the corridor. The Metro's directive was then to plan the corridor with different characteristics from the BRT corridor initially planned as in street level.

In addition to total segregation, other criteria that guided the choice for the MNT were comfort, regularity of trip, reliability, non-polluting rolling stock, maintenance of integration between communities in the region, good solar lighting on the street and connectivity and integration with the ticketing system of from the Subway (MNT and Subway integration at VPM Station. The maximum transport load was estimated at 340 thousand passengers per day, with a peak load of 33 thousand passengers/hour/direction between VPM and SMT. And the operational load estimated at 330,000 passengers/day with peak loading of 30,000 passengers/hour/direction. After studies, the chosen system was the MNT.

The construction of the MNT was planned to take place in three stages, with a total of 17 stations: the stretch between the VPM and Oratório (ORT) stations, which is 2.9 km long; the stretch to connect ORT to SMT, with 10 km and 7 intermediate stations; and the remaining stretch to connect SMT and HCT, with 11.5 km and 6 more stations (Figure 20).

Figure 20 - Line 15 Silver - São Paulo Metro Monorail.
Source: MECCA, 2013.

The total transport demand with the three stages installed was estimated at 550 thousand passengers per day and the simulations carried out by the Subway technicians, with mathematical models, indicated 40 thousand passengers hour/direction at peak times. The maximum project offer was set at 48,000 seats/hour/direction during peak hours. The MNT fleet to handle the loading between VPM and SMT was estimated in 27 trains and between

VPM and HCT in 54 trains. MNT trains are composed of 7 cars to carry 1000 passengers with internal comfort for 6 passengers per m^2. The estimated average commercial speed for the line is 35 to 40 km/h per hour and the maximum speed is 80 km/h. The maximum waiting time between trains (headway) at peak intervals is 90s. The system covers the Anhaia Melo, Sapopemba and Ragueb Chohfi avenues. Items such as the shading caused by the elevated roadway, the area occupied in the road street system and the degree of interference in the region of the work during construction were also elements considered in the subway technicians studies when defining the MNT modal (CADES, 2011; CADES, 2011; EPAMINONDAS, 2011; MECA, 2011; MECA, 2013; METRO, 2017).

There are no records about the elements that led to the exclusion of the LRT modal in the technical studies. However, this mode, as in the case of the BRT, it could be built completely segregated, in an elevated design to avoid road traffic interference, as well as in a semi-segregated option at level. Both in the BRT and LRT modes, in elevated design, would have to have their vehicles traveling on rolling infrastructure built on concrete decks, similar to, for example, the elevated system Presidente João Goulart (Minhocão), built on Avenida Francisco Matarazzo or similar to the BRT Tiradentes Express (author's note).

Considering the information present in the consulted bibliography (BASANI, 2017, EPAMINONDAS, 2011; MECA, 2011; MECA, 2013; METRÔ, 2016; METRÔ, 2017) and collected (by the author) in meetings held with SPTrans technicians (September and October 2017), the functional unit of the case study of this work has the following macro definition: stretch of track limited between the VPM and SMT stations of the MNT; maximum transport load of 340 thousand passengers/day and 33 thousand p/h/s at peak intervals; operational loading of 330,000 passengers/day and 30,000 p/h/s at peak intervals; minimum average operating speed of 25 km/h; twenty hours of daily operation, 10 hours in peak regime and 10 hours in valley; possibility of using diesel oil by the BRT and electricity supplied by the National Interconnected System (SIN) for LRT and MNT; service life of 30 years; possibility of studying two options related to the segregation of the roadway infrastructure (for the BRT) and street level (for the LRT and MNT) – one of them considering fully segregated and elevated infrastructure in relation to the road street system for the three modes, and the other considering exclusive left-hand traffic lanes with traffic light priority for the BRT and LRT modes and an elevated lane for the MNT.

According to the Metro project, the MNT uses 27 trains for the section of the functional unit, with a capacity for 1,000 passengers each and a comfort level of 6 passengers per m^2 (EPAMINONDAS, 2011; MECA, 2011; MECA, 2013). These requirements are basic for the quantification of the number of vehicles of the BRT and LRT systems in this work.

As the objective of the decision problem is to compare the operational and functional performances of the three modes, common elements of the three modes that do not affect the result of the comparison are excluded from the functional unit. Common elements are the region (lots) for parking and maintenance of vehicles, the Operational Control Center, the telecommunications systems and the so-called auxiliary systems (tariff collection, escalators, elevators, water pumps and ventilation systems) (author's note).

Application of the Decision Support Model

Decision problem

The decision problem consists of comparing the operational and functional performances of the BRT, LRT and MNT modes configured to serve the functional unit as well as listing them in order of priority. Priority is calculated based on user preferences of stakeholders and the performance of the alternatives against the selected criteria and sub-criteria.

Criteria

The study criteria (CS, FEV, EE, QL, IA) were defined by the author to form a comprehensive set, in line with the precepts of sustainable urban mobility. To this end, the parameters associated with the criteria cover aspects of energy efficiency and socio-economic and environmental axes. The boundaries that separate these criteria can't, by their own, completely isolate the interrelationships between them.

The System Cost (CS) criterion is related to the economic and social axels in the sense that systems with lower costs can equip more kilometers of lines and favor a greater number of people.

The Economic and Financial Feasibility (VEF) criterion has affinities with the economic and social axes, as the economic feasibility of the enterprise sponsors direct and indirect jobs in the transport sector, remunerates investors and perpetuates services for users.

Energy Efficiency (EE) is a criterion linked to economic and environmental axes because less energy-intensive systems provide lower operating costs and pollute less.

Trip Quality (QV) is not only a social criterion, but is also linked to economic and environmental axes. Economically while generating benefits for users who migrate from individual to collective transport. This migration plays an important role in the environmental axis since the urban community can use their cars less on a daily basis, an action that contributes to reducing emissions to the environment; another direct consequence of the reduction of individual transport is the improvement in the traffic flow.

Finally, the Environmental Impact criterion (IA), in addition to the intrinsic affinity with the environmental axis, is also linked to the economic axis. Systems that cause less impact on the environment reduce costs in repairing the negative externalities of transport systems, such as damage to human health and to the environment.

These five criteria, with the exception of Energy Efficiency one, are broken down into 22 sub-criteria as described below.

System Cost (CS)

- Investments in lane infrastructure, comprising: rolling lane; embarkation and disembarkation points; electrical power traction distribution and energy capture system (CSII). In this analysis, which has the problem (goal) of making comparisons, the common elements to the three alternatives are not considered regarding costs;
- Investment in vehicles necessary to meet the system demand (CSIV);
- Energy cost to operate vehicles over the 30 years lifetime of the system (CSCE);
- Vehicle operation and maintenance cost throughout the useful life of the system (CSOMV).
- Cost of operation and maintenance of the track infrastructure throughout the life of the system (CSOMI);
- Cost for renewing the system (track and vehicle infrastructure) over the lifetime of the system (CSCR).

Economic and Financial Feasibility (VEF)

- Payback Time (VEFTRI);
- Internal Rate of Return (VEFTIR);
- Net Present Value (VEFVPL).

Energy Efficiency (EE)

- -

Trip Quality (QV)

- Safety: accident between system vehicles (QVSVS);
- Safety: accident between system vehicles and road system vehicles (QVSVV);
- Travel time (as a function of average vehicle speed) (QVVM);

- Trip (on schedule) punctuality (operation management function) (QVPV);
- Universal accessibility (QVAU);
- Passenger Information System (QVSIP);
- Level of noise produced in the vehicle's internal environment (QVRI).

Environmental Impacts (AI)

- Greenhouse Gas Emissions - GHG (CO_2eq) throughout the life of the system (vehicle emissions) (IAGEE);
- Area of the road (street) occupied by the system infrastructure (IASO);
- Visual aesthetic impact of the infrastructure in the city environment (IAVE);
- Division of the road (street) caused by the system infrastructure (IADV);
- Noise level produced in the environment external to the vehicle (caused by the vehicle (IARE);
- Interference (time and logistics) in the surroundings of the system during its implementation (IATI).

Case study Agents (Decision Maker, Analyst and Decision Agent)

The Decision Maker (TD) is a hypothetical entity. The Analyst is the author himself. Decision Agents with five different profiles were defined by the author. They participated in this research as guests with the aim of assigning the levels of importance (preferences) to the criteria and sub-criteria:

- Urban transport operator (O);
- User - Passenger (U);
- Neighbor, member of the community neighboring the system (V);
- Equipment and/or service provider (F); and
- Consultant and/or researcher of the transport sector (C).

The levels of importance followed the Fundamental Scale shown in Table 4.

Hierarchical structure of the decision problem

Figure 21 shows the hierarchical structure of the decision problem with four levels: problem definition and agents (Level 1); definition of criteria (Level 2); definition of the sub-criteria (Level 3) and definition of the three selected alternatives (Level 4).

Following the text, the same steps of the example developed are applied:

- Survey of the preferences of the decision-makers by criteria and sub-criteria: the individual preferences of agents of each of the five classes were aggregated via arithmetic mean and preferences of the five classes were aggregated via geometric mean, as recommended by the AHP method;
- Survey of the performance scores for each alternative in compliance with the criteria and sub-criteria;
- Calculation of priority vectors of criteria, sub-criteria and alternatives, always checking the consistency of vectors according to the technique of the AHP method;
- Synthesis of priority vectors and determination of the Global Indices GI(s) of each alternative;
- Analysis of results.

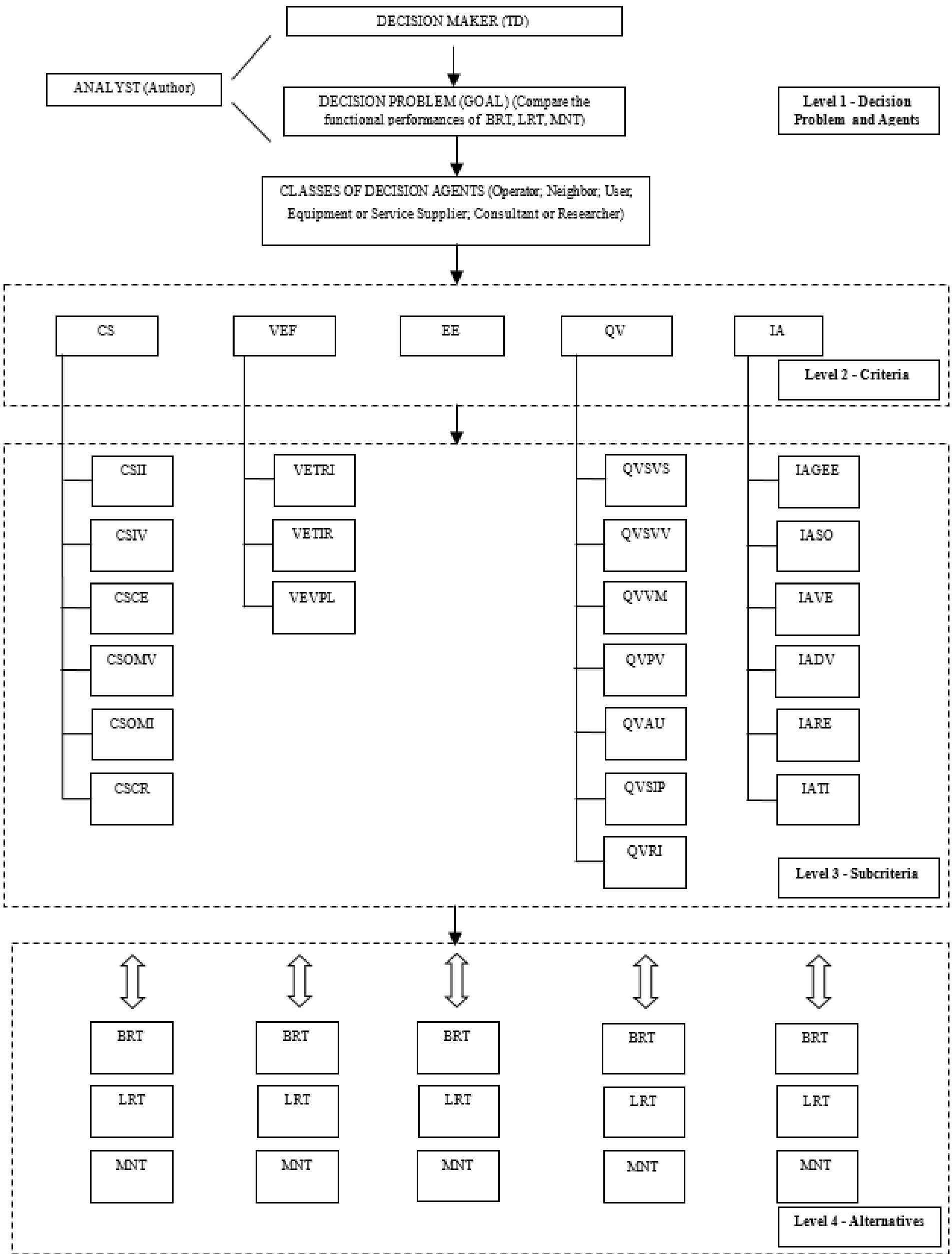

Figure 21 - Hierarchical structure of the case study decision problem.

RESULTS

PREFERENCES OF DECISION AGENTS

The decision agents' preferences for the criteria and sub-criteria were obtained in 138 consultations carried out via forms and interviews (Chart 4; Annex I).

The form suggested the respondent to participate with more than one profile, when applicable. Eighty-five of them were completed in direct interviews and the others were returned and discussed for clarification via e-mail. In summary, the responses obtained were:

Decision Agent *(Stakeholder)*	**Forms Received**	**Interviews**	**Sources of Information**
Operator	2	8	10
Neighbor	0	22	22
User	26	32	58
Equipment / Service Supplier	15	23	38
Consultant / Researcher	10	0	10
Total	53	85	138

Chart 4 - Preferences of Decision Agents - Study Forms and Interviews of the case study.
Source: Prepared by the author.

The process for identifying, collecting data, and analyzing data from decision makers (stakeholders) basically followed the steps indicated by Bryson (2011).

First, the candidates who could be invited were listed, taking into account the following conditions: availability and interest in the research; ease of contact to explain the questions form and arrange interviews; belong to one or more of the five profiles of agents of interest to the decision maker; ability to interpret and respond to the form and have a technical affinity or some relationship with public urban transport. In this case, the affinities were related to public transport in the city of São Paulo (Metrô, Monorail L15, CPTM, EMTU, and SPTRANS), experiences in acting as operators, neighbors, users, equipment or services suppliers of transportation area and consultants and researchers in the area of collective urban transport.

Then it was a matter of informing and agreeing with the collaborators how the form would be answered (via e-mail or interview).

The next steps consisted of receiving and evaluating the responses. Finally, the contributions received were formatted and incorporated into the research.

Table 18 summarizes the data representing the preferences of the stakeholders by the criteria. Remembering, these preferences were obtained in interviews and responses to forms. These data are the basis for building the VPC vector shown in Table 20.

Criteria - Decision agents' preferences (O: Operator; V: Neighbor; U: User; F: Supplier; C: Consultant)						
Decision Agents	O	V	U	F	C	Aggregation – Average Geometric of preferences (**values that are submitted to pairwise comparison**)
Evaluation forms	10	22	58	38	10	
Criteria	**Criteria** - Arithmetic mean of preferences					
Cost (CS)	7,1800	3,9091	4,3155	6,4342	4,7500	5,1723
Economic Financial Feasibility (VEF)	7,6380	3,7273	4,3716	6,6000	3,4500	4,9031
Energy Efficiency (EE)	8,1750	5,0000	4,4375	6,1000	4,6667	5,5282
TRIP Quality (QV)	6,3980	7,0000	7,6164	5,6237	4,9500	6,2446
Environmental Impact (IA)	5,2400	8,0000	5,9241	5,6224	4,6000	5,7749

Table 18 - Criteria - Preferences of Decision Agents - Case Study.
Source: Prepared by the author.

Figures 22 to 26, prepared with the data from Table 18, illustrate how each criterion (the criterion is the focus of the figure) is evaluated by each class of stakeholder. Pay attention to the fact that the data shown in this Table 18 are prior to the process of pairwise comparison and normalization.

The preferences show that the scenario in which the Decision Maker would have to manage has: the classes of **operators and manufacturers** with priorities for Energy Efficiency, Economic and Financial Feasibility and Costs; **Users**, with priority for the Quality of the Trip and the **Neighbors** of the system, with priority for environmental impacts.

Table 19 summarizes the data representing the preferences of the stakeholders by the subcriteria. These data are the basis for the construction of the Priority Subcriteria Vector (VPSC).

Annex II brings all the preference tables of the classes of stakeholders that were developed for the criteria and sub-criteria.

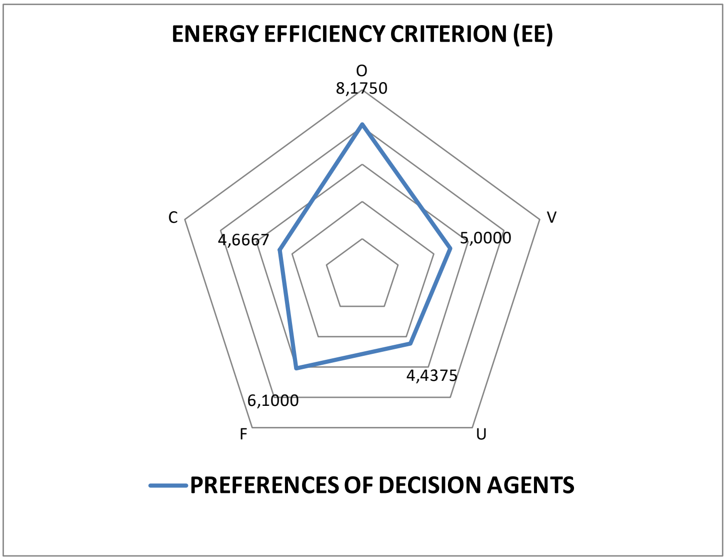

Figure 22 - Energy Efficiency - Preferences.
Source: Prepared by the author.

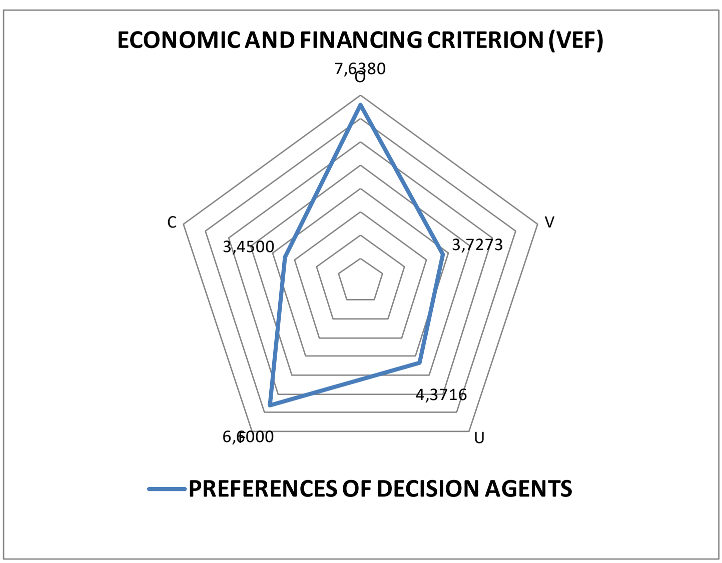

Figure 23 - Economic and Financial Feasibility - Decision Agents' Preferences.
Source: Prepared by the author.

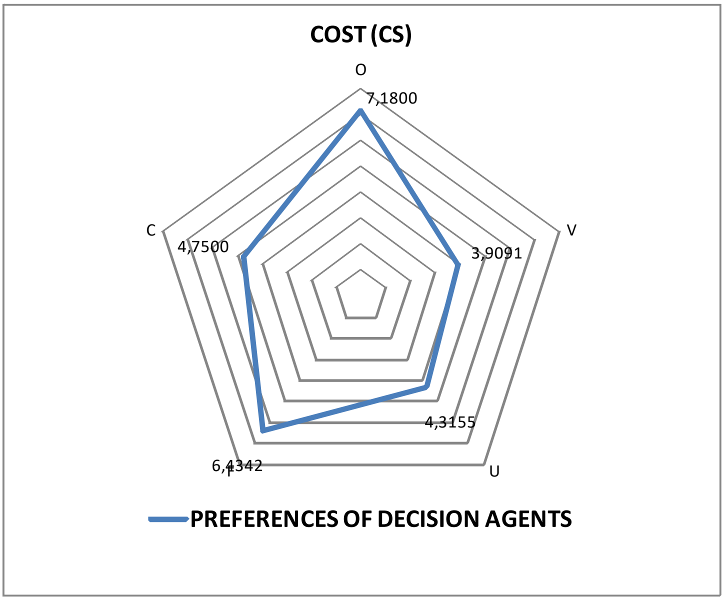

Figure 24 - Cost - Decision Agents' Preferences.
Source: Prepared by the author.

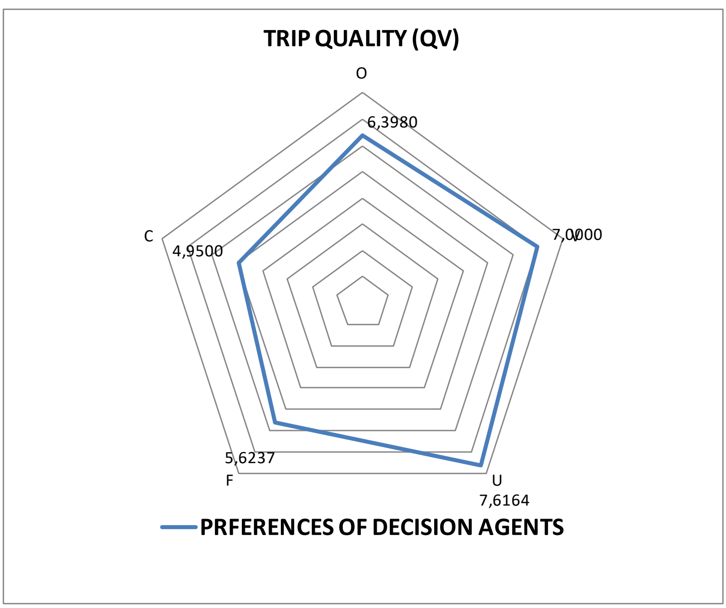

Figure 25 - Trip Quality - Decision Agents' Preferences.
Source: Prepared by the author.

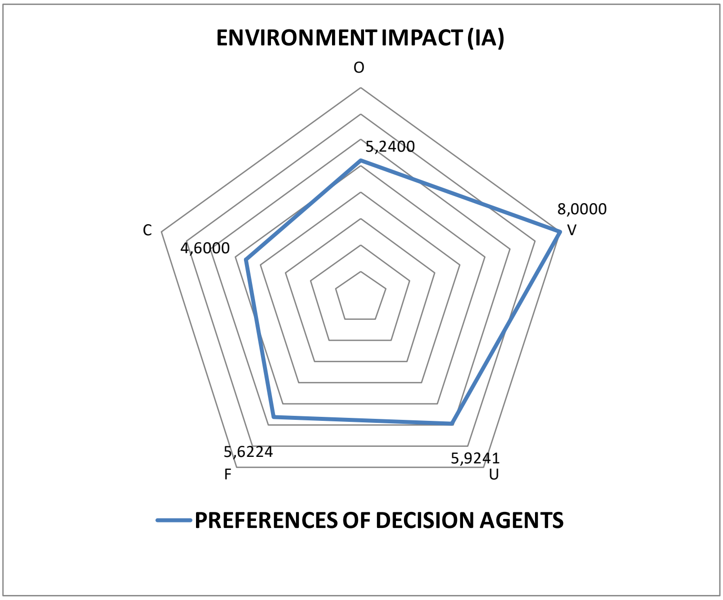

Figure 26 - Environmental Impact - Decision Agents' Preferences.
Source: Prepared by the author.

Subcriteria - Preferences of decision Agents (O: Operator; V: Neighbor; U: User; F: Manufacturer; C: Consultant)							
Agentes de decisão		O	V	U	F	C	Aggregation - Geometric Average - preferences (**values that will be submitted to pairwise comparison**)
Formulários de avaliação		10	22	58	38	10	
Critério	**Subcritério**	**Subcritérios** - Média Aritmética das preferências					
CS	CSII	7,1700	5,3636	5,3698	6,1039	5,8500	5,9366
	CSIV	6,2250	4,8182	5,4629	6,1513	4,8500	5,4680
	CSCE	7,1800	3,3636	4,3759	5,6776	4,4500	4,8451
	CSOMV	7,0500	3,3636	4,3578	5,7829	4,9250	4,9404
	CSOMI	6,2750	3,1818	3,9388	5,4658	4,1500	4,4696
	CSCR	6,3556	4,0909	4,1238	6,8000	1,8500	4,2266
VEF	VEFTRI	5,2500	3,0909	3,2845	6,1447	4,4000	4,2829
	VEFTIR	6,5556	2,2727	2,8938	6,5833	6,1667	4,4527
	VEFVPL	6,1000	2,1818	2,9298	5,5368	3,4444	3,7521
EE	EE						

QV	QVSVS	7,9100	7,6364	7,9052	8,1816	7,3000	7,7808
	QVSVV	7,6000	7,6364	7,6310	7,9132	7,4000	7,6344
	QVVM	6,8300	5,9091	6,5181	5,9697	4,6500	5,9251
	QVPV	6,9700	6,4545	7,3966	6,6184	6,0750	6,6878
	QVAU	5,4000	5,8182	6,4310	6,0066	4,8250	5,6691
	QVSIP	6,7500	4,9091	6,1147	5,6447	3,5750	5,2762
	QVRI	5,2500	5,0909	6,2703	5,8000	4,9500	5,4507
IA	IAGEE	6,1111	7,9091	6,2789	5,7632	4,9500	6,1303
	IASO	5,2400	6,7273	4,8371	4,3066	3,6750	4,8554
	IAVE	4,6500	6,8182	4,8009	4,5757	3,8500	4,8492
	IADV	5,0000	7,7273	4,7733	5,0842	3,6500	5,0917
	IARE	5,1800	8,2727	5,0862	5,0329	3,3750	5,1724
	IATI	4,2500	7,5455	4,8154	5,1913		5,3210

Table 19 - Subcriteria - Preferences of Decision Makers - Case Study.
Source: Prepared by the author.

Figure 27 shows another scenario, in which the preferences of stakeholders are aggregated via geometric mean. This aggregation shows the Quality criterion Travel in first place, with almost 50% of preferences, followed, in order, by Environmental Impacts, Energy Efficiency, and Cost and, with the lowest score, Economic and Financial Feasibility. The VPC vector is built with the aggregate preferences scenario.

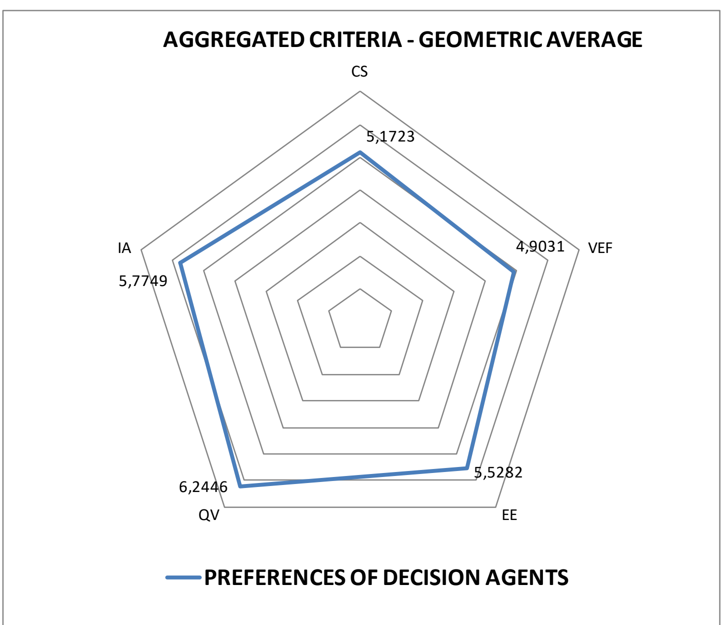

Figure 27 - Aggregate Criteria - Decision Agents' Preferences.
Source: Prepared by the author.

Criteria Priority (VPC) and Subcriteria Priority (VPSC) Vectors

The VPC and VPSC vectors, this last one composed of the VPSCS, VPSVEF, VPCEE, VPSQV and VPSIA vectors, are both shown in Table 20. The procedure for calculating the VPC and VPSC vectors has the same steps as the example developed in item 3.5, p.63: pairwise comparison matrix for criteria and sub-criteria, normalization, vectors calculations and consistency check. The difference between the example in item 3.5, p.63 and the case study is that, in this case, there are criteria that are broken down into sub-criteria. In other words, this case study has sub-criteria associated with CS (VPSCS), VEF (VPSVEF), QV (VPSQV) and IA (VPSIA) criteria. The energy efficiency (EE) criterion has no associated sub-criterion.

Importance (preferences) given by decision-makers to **criteria** (VPC) and **subcriteria** (VPSC) **after the pairwise comparison as per** the AHP method				
Critério	Subcritério	VPC	VPSC	Validation of the VPSC decomposition
CS	CSII	0,0810	0,4327	1,0000
	CSIV		0,2334	
	CSCE		0,0976	
	CSOMV		0,1454	
	CSOMI		0,0592	
	CSCR		0,0317	
VEF	VEFTRI	0,0372	0,2569	1,0000
	VEFTIR		0,6435	
	VEFVPL		0,0996	
EE	EE	0,1445	1,0000	1,0000
QV	QVSVS	0,4954	0,4079	1,0000
	QVSVV		0,2310	
	QVVM		0,0937	
	QVPV		0,1457	
	QVAU		0,0629	
	QVSIP		0,0198	
	QVRI		0,0390	
IA	IAGEE	0,2419	0,4414	1,0000
	IASO		0,0888	
	IAVE		0,0310	
	IADV		0,0639	
	IARE		0,1501	
	IATI		0,2249	

Table 20 - Criterion Priority Vector and Subcriteria Priority Vector - Study of Case.
Source: Prepared by the author.

Figures 28 to 32 illustrate the individualized preferences of each class of Stakeholders (scored in the center of the Figures) after pairwise comparison and normalization of scores. Figure 33 shows the preference of stakeholders in aggregate form according to Table 20.

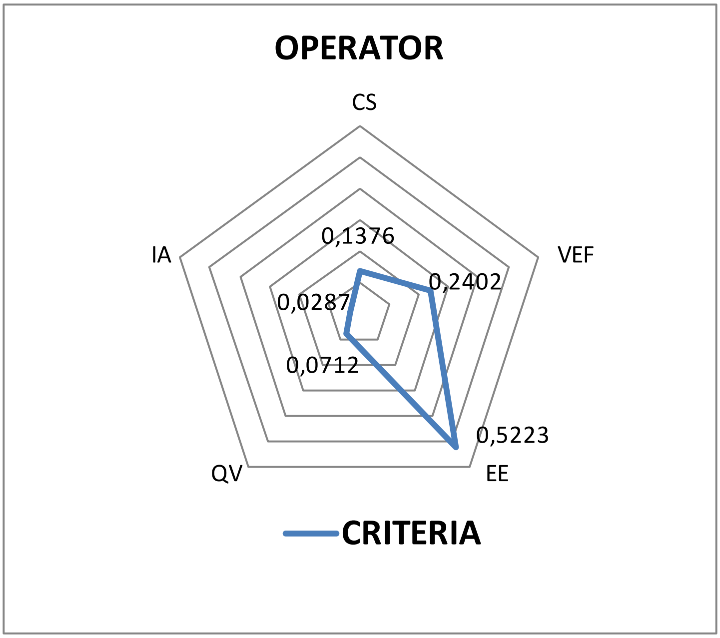

Figure 28 - Operator - Preferences.
Source: Prepared by the author.

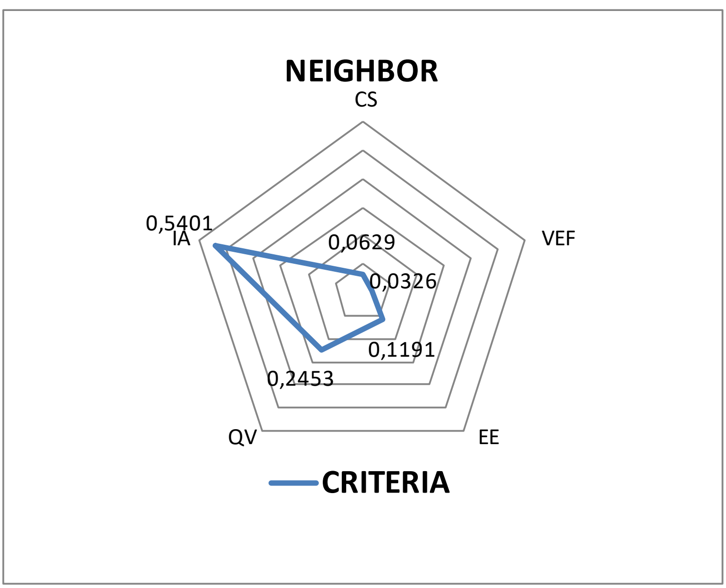

Figure 29 - Neighbor - Preferences.
Source: Prepared by the author.

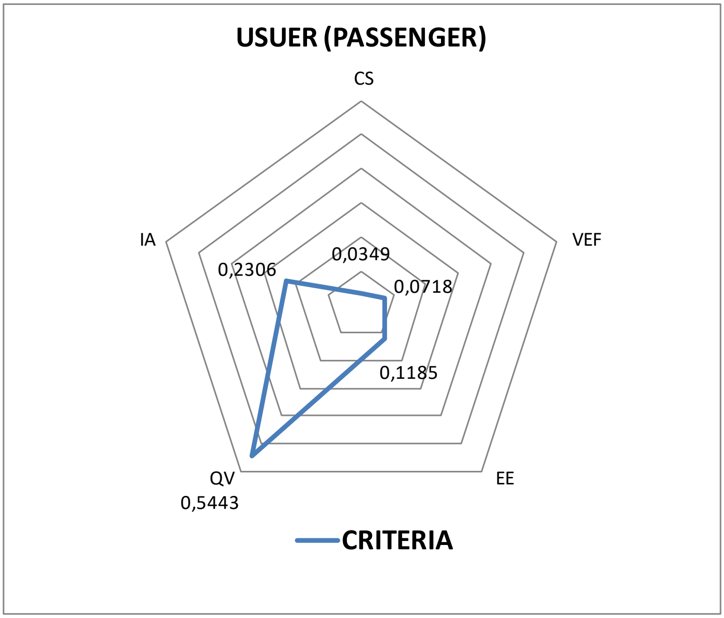

Figure 30 - User - Preference.
Source: Prepared by the author.

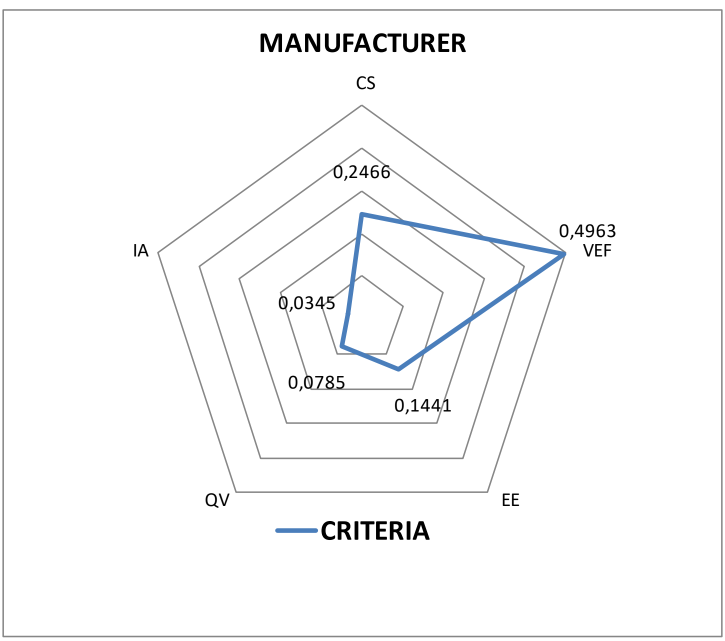

Figure 31 – Supplier(Equipment Manfacturer) - Preferences.
Source: Prepared by the author.

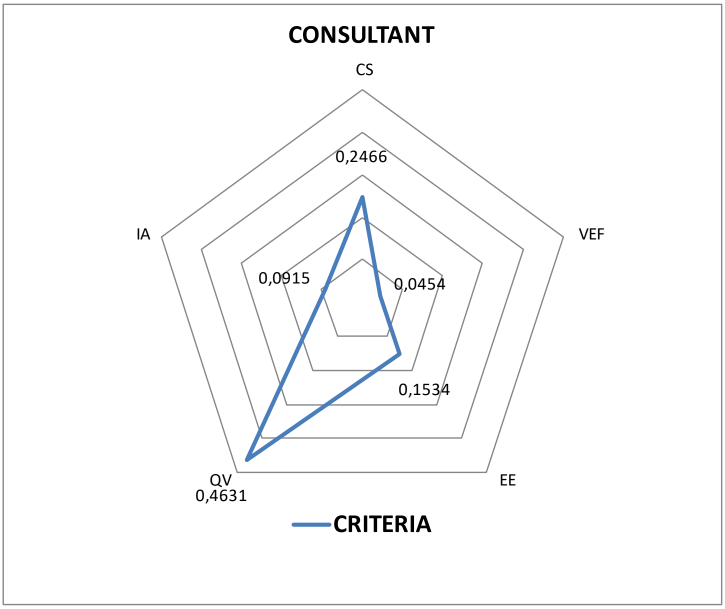

Figure 32 - Consultant - Preferences.
Source: Prepared by the author.

Individualized preferences clearly indicate the priorities of each of the agents: Operator - Energy Efficiency (EE); Neighbor - Environmental Impact (IA); User – Trip Quality (QV); Supplier of Equipment and Services, Economic and Financial Feasibility of the enterprise (VEF); and Consultants also have preferences for Trip Quality (QV).

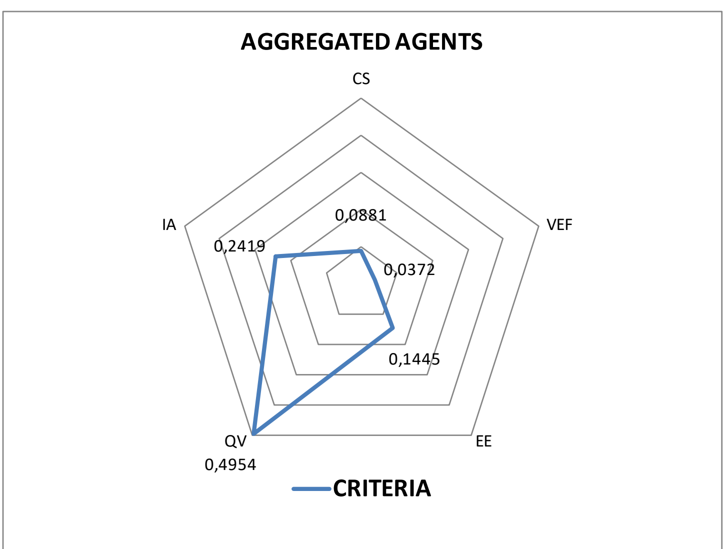

Figure 33 - Aggregated Agents - Preferences.
Source: Prepared by the author.

When the preferences of stakeholders are simply aggregated (see Table 20), the priority indicates an option for Trip Quality (QV). This is why the decomposition of preferences per agent is then important for the Decision Maker to evaluate in the final decision to take.

Tables 21, 22, 23, 24 and 25 show the pairwise comparison matrices of the criteria and sub-criteria already normalized and the final vectors found in the cells with gray marks.

CRITÉRIO	CS	VEF	EE	QV	IA	VPC
CS	0,0534	0,2181	0,0135	0,0976	0,0223	0,0810
VEF	0,0103	0,0422	0,0135	0,0976	0,0223	0,0372
EE	0,2950	0,2331	0,0747	0,0976	0,0223	0,1445
QV	0,3332	0,2633	0,4667	0,6096	0,8043	0,4954
IA	0,3081	0,2435	0,4316	0,0976	0,1288	0,2419

Table 21 - Normalized pairwise comparison matrix of criteria – Case Study.
Source: Prepared by the author.

Consistency Ratio: 0.0030, less than 0.10.

SUBCRITÉRIO	CSII	CSIV	CSCE	CSOMV	CSOMI	CSCR	VPSCS
CSII	0,5428	0,7742	0,3350	0,4561	0,2653	0,2230	0,4327
CSIV	0,0914	0,1304	0,3086	0,4201	0,2444	0,2054	0,2334
CSCE	0,0914	0,0238	0,0564	0,0157	0,2165	0,1820	0,0976
CSOMV	0,0914	0,0238	0,2767	0,0768	0,2191	0,1842	0,1454
CSOMI	0,0914	0,0238	0,0116	0,0157	0,0447	0,1679	0,0592
CSCR	0,0914	0,0238	0,0116	0,0157	0,0100	0,0376	0,0317

Table 22 - Normalized pairwise comparison matrix of subcriteria cost - Case Study.
Source: Prepared by the author.

Consistency Ratio: 0.0026, less than 0.10.

SUBCRITÉRIO	VEFTRI	VEFTIR	VEFVPL	VPSVEF
VEFTRI	0,1759	0,1550	0,4399	0,2569
VEFTIR	0,7831	0,6901	0,4574	0,6435
VEFVPL	0,0411	0,1550	0,1027	0,0996

Table 23 - Normalized pairwise comparison matrix of subcriteria economic and financial feasibility.
Case Study.
Source: Prepared by the author.

Consistency Ratio: 0.0021, less than 0.10.

SUBCRITÉRIO	QVSVS	QVSVV	QVVM	QVPV	QVAU	QVSIP	QVRI	VPSQV
QVSVS	0,5646	0,8246	0,3269	0,4574	0,2648	0,1938	0,2231	0,4079
QVSVV	0,0726	0,1060	0,3208	0,4488	0,2598	0,1902	0,2189	0,2310
QVVM	0,0726	0,0139	0,0420	0,0085	0,2017	0,1476	0,1699	0,0937
QVPV	0,0726	0,0139	0,2890	0,0588	0,2276	0,1666	0,1917	0,1457
QVAU	0,0726	0,0139	0,0071	0,0088	0,0340	0,1412	0,1625	0,0629
QVSIP	0,0726	0,0139	0,0071	0,0088	0,0060	0,0249	0,0053	0,0198
QVRI	0,0726	0,0139	0,0071	0,0088	0,0060	0,1358	0,0287	0,0390

Table 24 - Normalized pairwise comparison matrix of subcriteria quality of the trip - Case Study.
Source: Prepared by the author.

Razão de Consistência: 0.0038, menor que 0,10.

SUBCRITÉRIO	IAGEE	1ASO	IAVE	IADV	IARE	IATI	VPSIA
IAGEE	0,5508	0,3430	0,2223	0,2852	0,4702	0,7767	0,4414
1ASO	0,0898	0,0560	0,1761	0,1712	0,0151	0,0245	0,0888
IAVE	0,0898	0,0115	0,0363	0,0087	0,0151	0,0245	0,0310
IADV	0,0898	0,0152	0,1930	0,0465	0,0148	0,0238	0,0639
IARE	0,0898	0,2849	0,1847	0,2407	0,0767	0,0238	0,1501
IATI	0,0898	0,2894	0,1876	0,2476	0,4081	0,1267	0,2249

Table 25 - Normalized pairwise comparison matrix of subcriteria environment impact - Case Study.
Source: Prepared by the author.

Consistency Ratio: 0.0026, less than 0.10.

Having calculated the VPC and VPSC vectors, the next step in the process deals with the calculation of the VPA vector. This vector depicts the performance of each of the alternatives in relation to each of the criteria and subcriteria.

PERFORMANCES OF ALTERNATIVES (VPA)

Chart 5 shows the possibilities that can be simulated to obtain the global indices that will be made available to the Decision Maker (TD). Remembering, the model that is used must be understood as a support tool, which presents scenarios that help the TD to make the final decision on what will be the best alternative to solve your problem.

In this Case Study two scenarios are simulated as highlighted in the gray cells of **Chart 5**. They consider the preferences of decision-makers aggregated in geometric mean and two possibilities for installing infrastructure (one, with elevated lanes for the three modes; and the other, elevated for MNT and at street level for BRT and LRT. The two possibilities for installing the infrastructure of the BRT mode were discussed by the author with technicians from SPTrans (São Paulo Bus Authority) who confirmed, for the purpose of studies, the operational feasibility of these alternatives for BRT systems in applications with the transport load of the functional unit of the case study. This feasibility for BRT was considered (note of the author) as also valid for the LRT. The LRT, by the way, has an advantage over the BRT due to the fact that the vehicles have more internal capacity and can travel with coupled units, which facilitates the management of fleet capacity according to the passenger load, then meeting the requirement defined in the functional unit.

The purpose of these two simulations is to verify what happens with the global indices of the alternatives, since the infrastructure costs at street level of the BRT and LRT modes are lower than the elevated infrastructure of the MNT. On the other hand, the infrastructure at the street level in exclusive lanes with traffic light priority will affect the score of the sub-criteria that deal with the safety of road vehicles, average speed and occupation and division of the street road system.

Stakeholders Decision Agents	Preferences of Stakeholders for Criteria and Subcriteria		Performances of Alternatives		Global Index (IG)		
	Individual Preferen-ces	Aggregated Preferences (Geometric Mean	Elevated Infrastructure MNT, BRT, LRT	MNT Elevated Infra; BRT LRT: Street Level Infra	BRT	LRT	MNT
O (Operator)							
V (Neighbor)							
U (User)							
F (Manufacturer)							
C (Consultant)							

Chart 5 - Options for analysis of results - Case Study.
Source: Prepared by the author.

VPA - Elevated Infrastructure

Table 26 shows the VPA for each modal that was obtained from the following considerations: elevated infrastructure for the three modes; estimates of the performance of each modal in relation to the requirements of the functional unit are raised by the author in bibliographic research and in field observations and measurements; elaboration of pairwise comparison matrices, normalization and consistency checks.

Criteria	Subcriteria	VPA – Performances of the modes in each **criterion and subcriterion after the pairwise comparison** – Elevated Infra			
		BRT	LRT	MNT	Consistency check of the decomposition of the individuals performances
CS	CSII	0,5508	0,1732	0,2761	1,0000
	CSIV	0,8081	0,0610	0,1309	1,0000
	CSCE	0,0630	0,2232	0,7138	1,0000
	CSOMV	0,0829	0,2385	0,6786	1,0000
	CSOMI	0,0912	0,2453	0,6635	1,0000
	CSCR	0,3333	0,3333	0,3333	1,0000
	VEFTRI	0,1576	0,1860	0,6564	1,0000
	VEFTIR	0,1670	0,1780	0,6549	1,0000
	VEFVPL	0,0624	0,0854	0,8522	1,0000
EE	EE	0,0695	0,2287	0,7018	1,0000
	QVSVS	0,0529	0,2114	0,7357	1,0000
	QVSVV	0,3333	0,3333	0,3333	1,0000
	QVVM	0,3333	0,3333	0,3333	1,0000
	QVPV	0,0546	0,2004	0,7450	1,0000
	QVAU	0,0909	0,8182	0,0909	1,0000
	QVSIP	0,0546	0,2004	0,7450	1,0000
	QVRI	0,2893	0,3236	0,3872	1,0000
	IAGEE	0,1464	0,2801	0,5735	1,0000
	IASO	0,1988	0,1988	0,6024	1,0000
	IAVE	0,1111	0,1111	0,7778	1,0000
	IADV	0,3333	0,3333	0,3333	1,0000
	IARE	0,2893	0,3236	0,3872	1,0000
	IATI	0,1233	0,2189	0,6578	1,0000

Table 26 - Alternative Priority Vector (VPA) - Case Study.
Elevated Infrastructure for the three modes.
Source: Prepared by the author.

The items that follow show the pairwise comparison matrices of the performances of each modal, already normalized, and the consistency indices.

The Annex III shows in detail the calculations and assumptions adopted to estimate the performance of each of the three alternatives in relation to each of the subcriteria. The calculated values are summarized in Table AIII-4 (Annex III).

Cost - Pairwise Comparison Matrix

Performance - Subcriterion Investment in track Infrastructure (CSII)

The estimated investments (costs in US$ mi/km) in track infrastructure are: BRT, 39.00; LRT, 59.00 and MNT, 49.32.

Comparison matrix and performance priority vector (1/cost) CSII

FACTOR	CSII BRT	CSII VLT	CSII MNT	VPA CSII
CSII BRT	0,5618	0,4586	0,6320	0,5508
CSII VLT	0,2191	0,1788	0,1216	0,1732
CSII MNT	0,2191	0,3626	0,2465	0,2761

Table 27 - Normalized pairwise comparison matrix of CSII performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0.00004, less than 0.10.

Performance - Subcriteria Investment in Vehicles (CSIV)

The estimated investments (costs in US$ mi) in vehicles are: BRT fleet, 100.2; LRT Fleet, 432.0; and MNT Fleet, 321.3.

Comparison matrix and performance priority vector (1/cost) of the CSIV subcriterion

FACTOR	CSIV BRT	CSIV VLT	CSIV MNT	VPA CSIV
CSIV BRT	0,8331	0,7082	0,8831	0,8081
CSIV VLT	0,0835	0,0710	0,0284	0,0610
CSIV MNT	0,0835	0,2209	0,0885	0,1309

Table 28 - Normalized pairwise comparison matrix of performances - CSIV- Case study.
Source: Prepared by the author.

Consistency Ratio: 0.0013, less than 0.10.

Performance - Subcriterion Cost of Energy to operate vehicles over the lifetime (30 years) of the system (CSCE)

The energy cost calculated for the operation of vehicles over 30 years of operation, for each modal in Brazilian R$, are: BRT, 2,382,505,120.00; LRT, 1,470,643,776.00; MNT, 1,347,192,000.00.

Comparison matrix and performance priority vector (1/cost) of the CSCE subcriterion

FATOR	CSCE BRT	CSCE VLT	CSCE MNT	VPA CSCE
CSCE BRT	0,0657	0,0172	0,1061	0,0630
CSCE VLT	0,4467	0,1167	0,1061	0,2232
CSCE MNT	0,4876	0,8662	0,7877	0,7138

Table 29 - Normalized pairwise comparison matrix of performances - CSCE - Case study.
Source: Prepared by the author.

Consistency Ratio: 0.0039, less than 0.10.

Performance - Vehicle Operation and Maintenance Cost Sub-criteria (CSOMV)

Based on the bibliography consulted, the estimated daily operating costs in Brazilian R$ for the operation of each modal are: CSOMV: BRT, 336,600.00; LRT, 199,000.00; MNT, 180,540.00.

Comparison matrix and performance priority vector (1/cost) of the CSOMV subcriterion

FATOR	CSOMV BRT	CSOMV VLT	CSOMV MNT	VPA CSOMV
CSOMV BRT	0,0865	0,0295	0,1326	0,0829
CSOMV VLT	0,4345	0,1484	0,1326	0,2385
CSOMV MNT	0,4790	0,8221	0,7347	0,6786

Table 30 - Normalized pairwise comparison matrix of performances - CSOMV - Case Study.
Source: Prepared by the author.

Consistency Ratio: 0.0026, less than 0.10.

Performance - Subcriterion Cost of Operation and Maintenance of Track Infrastructure CSOMI)

Based on the bibliography consulted, the estimated (in Brazilian R$) daily track maintenance costs of each modal are: CSOMVI: BRT, 37,400.00; VLT, 22,000.00; and MNT, 20,600,000.

Comparison matrix and performance priority vector (1/cost) of the CSOMI subcriterion

FACTOR	CSOMI BRT	CSOMI VLT	CSOMI MNT	VPA CSOMI
CSOMI BRT	0,0950	0,0355	0,1432	0,0912
CSOMI VLT	0,4316	0,1612	0,1432	0,2453
CSOMI MNT	0,4734	0,8034	0,7137	0,6635

Table 31 - Normalized pairwise comparison matrix of performances - CSOMI - Case study.
Source: Prepared by the author.

Consistency Ratio: 0.0023, less than 0.10.

Performance - Subcriterion Cost to renew the system over its useful life (CSCR)

The CSCR sub-criteria score assigned to each modal is: BRT, 0.3333; VLT, 0.3333; and MNT, 0.3333. The logic for this assignment is described in the Annex III.

Comparison matrix and performance priority vector (1/cost) of the CSCR subcriterion

FACTOR	CSCR BRT	CSCR LRT	CSCR MNT	VPA CSCR
CSCR BRT	0,3333	0,3333	0,3333	0,3333
CSCR LRT	0,3333	0,3333	0,3333	0,3333
CSCR MNT	0,3333	0,3333	0,3333	0,3333

Table 32 - Normalized pairwise comparison matrix of CSCR performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0.0, less than 0.10.

Economic and Financial Feasibility - Comparison Matrix Pairwise

In this item, the BRT, VLT and MNT systems are compared in terms of their own capacity to generate cash, pay operating costs and remunerate shareholders' investments at an arbitrated discount rate. The sub-criteria analyzed were TRI, IRR and VLP. The cost of the infrastructure through which the vehicles travel are not considered in this analysis, because they are too high to be financed by the operational results of the project.

Performance - Payback Time Subcriterion (VEFTRI)

The calculated values were: for the BRT (VEFTRI BRT) - 9.8 years; for the LRT (VEFTRI LRT) - 7.8 years and for the MNT (VEFTRI MNT) - 2.6 years.

Comparison matrix and performance priority vector (1/TRI) of the VEF sub-criterion

FACTOR	VEFTRI BRT	VEFTRI LRT	VEFTRI MNT	VPA VEFTRI
VEFTRI BRT	0,1632	0,1386	0,1711	0,1576
VEFTRI LRT	0,2092	0,1777	0,1711	0,1860
VEFTRI MNT	0,6276	0,6836	0,6579	0,6564

Table 33 - Normalized pairwise comparison matrix of VEFTRI performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 5,9 E-5, less than 0.10.

Performance - Internal Rate of Return (VEFTIR) sub-criteria

The calculated values were: for BRT (VEFTIR BRT) - 7.0%; for the LRT (VEFTIR LRT) -11.0% and for the MNT (VEFTIR MNT) - 38.0%.

Comparison matrix and performance priority vector (TIR) of the subcriterion VEF

FACTOR	VEFTIR BRT	VEFTIR LRT	VEFTIR MNT	VPA VEFTIR
VEFTIR BRT	0,1695	0,1592	0,1724	0,1670
VEFTIR LRT	0,1864	0,1752	0,1724	0,1780
VEFTIR MNT	0,6441	0,6556	0,6552	0,6549

Table 34 - Normalized pairwise comparison matrix of VEFTIR performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 8,7 E-6, less than 0.10.

Performance - Net Present Value Subcriteria (VEFVPL)

The values calculated in US$ mi were: BRT (VEFVPL BRT) - 14.2; LRT (VEFVPL LRT) - 1,600.0 and MNT (VEFVPL MNT) - 11,900.00.

Comparison matrix and performance priority vector (VPL) of the VEF subcriterion

FACTOR	VEFVPL BRT	VEFVPL LRT	VEFVPL MNT	VPA VEFVPL
VEFVPL BRT	0,0690	0,0462	0,0719	0,0624
VEFVPL LRT	0,1103	0,0739	0,0719	0,0854
VEFVPL MNT	0,8207	0,8799	0,8561	0,8522

Table 35 - Normalized pairwise comparison matrix of VEFVPL performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 2,1 E-3, less than 0.10.

Energy Efficience - Pairwise Comparison Matrix

The metric used to assess Energy Efficiency is 1/Energy Intensity. The Energy Intensity is the amount of energy (Tj) used by the system during the entire life cycle operation in the functional unit.

Performance - Energy Efficiency (EE)

This criterion has no associated sub-criteria. The amounts of energy intensity calculated as described in Annex III are: BRT - 27.07 Tj; LRT - 16,34 Tj; and MNT 14,97 Tj.

Comparison matrix and performance priority vector of the EE criterion

FACTOR	EE BRT	EE LRT	EE MNT	VPA EE
EE BRT	0,0725	0,0208	0,1152	0,0695
EE LRT	0,4435	0,1275	0,1152	0,2287
EE MNT	0,4841	0,8517	0,7696	0,7018

Table 36 - Normalized pairwise comparison matrix of EE performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0034 E-3, less than 0.10.

Trip Quality - Pairwise Comparison Matrix

Performance - Subcriterion Safety distances between the vehicles of the system (QVSVS)

In this sub-criterion, each of the three modalities receives a subjective score (author), between 1.0 and 10.0 according to the scenario in which each one of them operates in the functional unit, in relation to the modalities completely manual with no safety supervision, safety supervised manual and completely safety automatic. The scores awarded are: BRT - 7.0; LRT - 8.0 and MNT - 9.0. Annex III provides more information on the attribution of these scores.

Subcriteria performance comparison matrix and priority vector (QVSVS)

FACTOR	QVSVS BRT	QVSVS LRT	QVSVS MNT	VPA QVSVS
QVSVS BRT	0,0556	0,0123	0,0909	0,0529
QVSVS LRT	0,4444	0,0988	0,0909	0,2114
QVSVS MNT	0,5000	0,8889	0,8182	0,7357

Table 37 - Normalized pairwise comparison matrix of QVSVS performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0004, less than 0.10.

Performance - Subcriterion Safety distances between the vehicles of the system and the road system (QVSVV)

In this sub-criterion, the three modes receive the same score (level 10.0), because the Functional Unit defines that the three ones must operate on an elevated lane, segregated from the street road traffic.

Subcriteria performance comparison matrix and priority vector (QVSVV)

FACTOR	QVSVV BRT	QVSVV LRT	QVSVV MNT	VPA QVSVV
QVSVV BRT	0,3333	0,3333	0,3333	0,3333
QVSVV LRT	0,3333	0,3333	0,3333	0,3333
QVSVV MNT	0,3333	0,3333	0,3333	0,3333

Table 38 - Normalized pairwise comparison matrix of QVSVV performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0000, less than 0.10.

Performance - Average Vehicle Speed (QVM) sub-criterion

The functional unit requires a minimum operating speed of 35 km/h. The consulted bibliography informs that the three modes can meet this requirement, as long as the projects have adequate characteristics in infrastructure and functionalities. With this argument, the same score (10.0) is assigned to the three modes. Annex III describes some operational strategies that can be adopted by each modality in order to meet the speed required by the functional unit.

Subcriteria performance comparison matrix and priority vector (QVVM)

FACTOR	QVVM BRT	QVVM LRT	QVVM MNT	VPA QVVM
QVVM BRT	0,3333	0,3333	0,3333	0,3333
QVVM LRT	0,3333	0,3333	0,3333	0,3333
QVVM MNT	0,3333	0,3333	0,3333	0,3333

Table 39 - Normalized pairwise comparison matrix of QVVM performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0000, less than 0.10.

Performance - Trip On-schedule Subcriterion (QVPV)

In this sub-criterion, each of the modes received a score on a scale between 1 and 10, according to the level of the technical capability available to monitoring and control the programmed trip schedule of the system.

Each modal was scored, subjectively (author), on a scale from 1 to 10: BRT - 5.0; LRT - 7.0 and MNT - 9.0. Annex III provides more information on the attribution of these values.

Subcriteria performance comparison matrix and priority vector (QVPV)

FACTOR	QVQPV BRT	QVQPV LRT	QVQPV MNT	VPA QVQPV
QVQPV BRT	0,0588	0,0141	0,0909	0,0546
QVQPV LRT	0,4118	0,0986	0,0909	0,2004
QVQPV MNT	0,5294	0,8873	0,8182	0,7450

Table 40 - Normalized pairwise comparison matrix of QVQPV performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0019, less than 0.10.

Performance - Universal Accessibility Subcriterion (QVAU)

In this sub-criterion, each modal received a score on a scale between 1 and 10, according to the level of the available gait monitoring and control system.

Each modal was scored, subjectively (author), on a scale from 1 to 10, in: BRT - 7.0; VLT - 9.0 and MNT - 7.0. Annex III provides more information on the attribution of these values.

Subcriteria performance comparison matrix and priority vector (QVAU)

FACTOR	QVQVAU BRT	QVQVAU LRT	QVQVAU MNT	VPA QVQVAU
QVQVAU BRT	0,0909	0,0909	0,0909	0,0909
QVQVAU LRT	0,8182	0,8182	0,8182	0,8182
QVQVAU MNT	0,0909	0,0909	0,0909	0,0909

Table 41 - Normalized pairwise comparison matrix of QVQVAU performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0000, less than 0.10.

Performance - Passenger Information System (QVSIP) Sub-criteria

In this sub-criterion, each of the modes received a score on a scale between 1 and 10, according to the level of the available gait monitoring and control system.

Each modal was scored, subjectively (author), on a scale from 1 to 10, in: BRT - 6.0; VLT - 7.0 and MNT - 9.0. Annex III provides more information on the attribution of these values.

Subcriteria performance comparison matrix and priority vector (QVSIP)

FACTOR	QVQVSIP BRT	QVQVSIP LRT	QVQVSIP MNT	VPA QVQVSIP
QVQVSIP BRT	0,0588	0,0141	0,0909	0,0546
QVQVSIP LRT	0,4118	0,0986	0,0909	0,2004
QVQVSIP MNT	0,5294	0,8873	0,8182	0,7450

Table 42 - Normalized pairwise comparison matrix of QVQVSIP performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0004, less than 0.10.

Performance - Vehicle Internal Noise Level (QVRI)

The values considered in this sub-criterion are: BRT - 86.5 db(A); LRT - 84.5 db(A) and MNT - 79.0 dbA. Annex III provides information on obtaining these indices.

Subcriteria performance comparison matrix and priority vector (QVRI)

FACTOR	QVQVRI BRT	QVQVRI LRT	QVQVRI MNT	VPA QVQVRI
QVQVRI BRT	1,0000	0,8450	0,7900	0,2893
QVQVRI LRT	1,1834	1,0000	0,7900	0,3236
QVQVRI MNT	1,2658	0,2658	1,0000	0,3872

Table 43 - Normalized pairwise comparison matrix of QVQVRI performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 2,71 E-05, less than 0.10.

Environmental Impact - Pairwise Comparison Matrix

Performance - Greenhouse Gas Emissions Sub-criteria - (IAGEE)

The evaluation of this sub-criterion, GEE emissions by vehicles, adopts as an indicator the amount of CO_2 gas (CO_2eq) that is released into the atmosphere in the region of the vehicles' street-way and also globally, outside the street-way. The estimated emissions (author) for the modes are: BRT - 2,294,421 tCO_2eq; LRT - 370,838 tCO_2eq and MNT - 339,709 tCO_2eq. See the memorandum for calculating these emissions in Annex III.

Subcriteria performance comparison matrix and priority vector (IAGEE)

FACTOR	IAGEE BRT	IAGEE LRT	IAGEE MNT	VPA IAGEE
IAGEE BRT	0,1507	0,0860	0,2024	0,1464
IAGEE LRT	0,4061	0,2319	0,2024	0,2801
IAGEE MNT	0,4432	0,6821	0,5952	0,5735

Table 44 - Normalized pairwise comparison matrix of IAGEE performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 9,5 E-05, less than 0.10.

Performance - Sub-criterion area of the road system occupied by the road infrastructure (IASO)

The scores awarded for each mode are: BRT - 7.94 m; LRT - 7.94 m and MNT - 3.3 m. See the arguments regarding these values in Annex III.

Subcriteria performance comparison matrix and priority vector (IASO)

FACTOR	IAIASO BRT	IAIASO LRT	IAIASO MNT	VPA IAIASO
IAIASO BRT	0,1988	0,1988	0,1988	0,1988
IAIASO LRT	0,1988	0,1988	0,1988	0,1988
IAIASO MNT	0,6024	0,6024	0,6024	0,6024

Table 45 - Normalized pairwise comparison matrix of IAGEE performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0, less than 0.10.

Performance - Sub-criteria visual aesthetic impact of the road infrastructure (IAVE)

The scores for this sub-criterion were assigned on a scale from 1.0 to 10, subjectively (author), depending on the constructive characteristics of the road infrastructure of each modal: BRT - 5.0; LRT - 5.0 and MNT - 7.0. See the arguments regarding these values in Annex III.

Subcriteria performance comparison matrix and priority vector (IAVE)

FACTOR	IAIAVE BRT	IAIAVE LRT	IAIAVE MNT	VPA IAIAVE
IAIAVE BRT	0,1111	0,1111	0,1111	0,1111
IAIAVE LRT	0,1111	0,1111	0,1111	0,1111
IAIAVE MNT	0,7778	0,7778	0,7778	0,7778

Table 46 - Normalized pairwise comparison matrix of IAIAVE performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 1,4 E-04, less than 0.10.

Performance - Subcriterion division of the road system caused by the road infrastructure (IADV)

In this sub-criterion, the three modes receive the same score (level 10), as the functional unit defines that the three ones must operate on elevated lanes, segregated from the street (road) traffic.

Subcriteria performance comparison matrix and priority vector (IADV)

FACTOR	IAIADV BRT	IAIADV LRT	IAIADV MNT	VPA IAIADV
IAIADV BRT	0,3333	0,3333	0,3333	0,3333
IAIADV LRT	0,3333	0,3333	0,3333	0,3333
IAIADV MNT	0,3333	0,3333	0,3333	0,3333

Table 47 - Normalized pairwise comparison matrix of IAIADV performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0, less than 0.10.

Performance - Subcriterion noise level produced in the environment external to the vehicle (IARE)

The values assigned to the three modes are: BRT - 88.5 db(A); LRT - 84.5 db(A) and MNT - 79.0 db(A). See Annex III for information on obtaining these indices.

Subcriteria performance comparison matrix and priority vector (IARE)

FACTOR	IAIARE BRT	IAIARE LRT	IAIARE MNT	VPA IAIARE
IAIARE BRT	1,0000	0,8450	0,7900	0,2893
IAIARE LRT	1,1834	1,0000	0,7900	0,3236
IAIARE MNT	1,2658	1,2658	1,0000	0,3872

Table 48 - Normalized pairwise comparison matrix of IAIARE performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 2,71 E-05, less than 0.10.

Performance - Subcriterion Interference (time and logistics) in the surroundings of the enterprise during the installation of the system (IATI)

The assessment of this sub-criterion adopts as an indicator the time to install the road infrastructure as defined in the functional unit. Times are estimated in months: BRT, 36 months; VLT, 42 months and MNT, 24 months. The arguments that indicated these times can be found in Annex III.

Subcriteria performance comparison matrix and priority vector (IATI)

FACTOR	IAIATI BRT	IAIATI LRT	IAIATI MNT	VPA IAIATI
IAIATI BRT	0,1325	0,0752	0,1622	0,1233
IAIATI LRT	0,3155	0,1790	0,1622	0,2189
IAIATI MNT	0,5521	0,7458	0,6757	0,6578

Table 49 - Normalized pairwise comparison matrix of IAIATI performances - Case study.
Source: Prepared by the author.

Consistency Ratio: 0,0011, less than 0.10.

VPA - High Infrastructure for MNT and at Level for BRT and VLT

The procedure for setting up the pairwise comparison matrices and the vectors of each sub-criterion, which lead to the calculation of the VPA for this infrastructure (installation) option, is the same as that used for the elevated infrastructure option (items 2.1.1 to 2.1.5). As the process is repetitive, only the VPA already assembled is shown - Table 50.

Criteria	Subcriteria	VPA - Performance of modals on each **criterion and subcriterion after Pairwise comparison** - Elevated Infa only for MNT			
		BRT	LRT	MNT	Consistency Check
CS	CSII	0,6933	0,1908	0,1159	1,0000
	CSIV	0,8081	0,0610	0,1309	1,0000
	CSCE	0,0630	0,2232	0,7138	1,0000
	CSOMV	0,0829	0,2385	0,6786	1,0000
	CSOMI	0,0912	0,2453	0,6635	1,0000
	CSCR	0,3333	0,3333	0,3333	1,0000
VEF	VEFTRI	0,1576	0,1860	0,6564	1,0000
	VEFTIR	0,1670	0,1780	0,6549	1,0000
	VEFVPL	0,0624	0,0854	0,8522	1,0000
EE	EE	0,0695	0,2287	0,7018	1,0000
QV	QVSVS	0,0529	0,2114	0,7357	1,0000
	QVSVV	0,0833	0,0833	0,8333	1,0000
	QVVM	0,3333	0,3333	0,3333	1,0000
	QVPV	0,0546	0,2004	0,7450	1,0000
	QVAU	0,0909	0,8182	0,0909	1,0000
	QVSIP	0,0546	0,2004	0,7450	1,0000
	QVRI	0,2893	0,3236	0,3872	1,0000

IA	IAGEE	0,1464	0,2801	0,5735	1,0000
	IASO	0,1988	0,1988	0,6024	1,0000
	IAVE	0,1111	0,1111	0,7778	1,0000
	IADV	0,1429	0,1429	0,7143	1,0000
	IARE	0,2893	0,3236	0,3872	1,0000
	IATI	0,1233	0,2189	0,6578	1,0000

Table 50 - Alternative Priority Vector (VPA) - Case Study - Infrastructure high only for MNT.
Source: Prepared by the author.

GLOBAL INDEX (IG)

Once the criteria, subcriteria and priority vectors for the two infrastructure alternatives have been calculated, the next step is to determine the Global Indices. They will indicate the final order of priority (or importance) of the three modes.

The Global Indices are calculated with Equations 31, 32 and 33, where ***m*** corresponds to the number of criteria (5 in this case) and ***p*** to the number of sub-criteria (22 in this case). All terms in these equations are shown in Annex VI.

- Global BRT Index Case Study.

$$IG(BRT) = \sum_{i=1}^{m} VPC(Ci) * \sum_{k=1}^{p} VPSC(Ck) * VPA(BRT) \quad \textbf{(31)}$$

- Global LRT (or VLT) Index - Case Study.

$$IG(VLT) = \sum_{i=1}^{m} VPC(Ci) * \sum_{k=1}^{p} VPSC(Ck) * VPA(VLT) \quad \textbf{(32)}$$

- Global MNT Index – Case Study.

$$IG(MNT) = \sum_{i=1}^{m} VPC(Ci) * \sum_{k=1}^{p} VPSC(Ck) * VPA(MNT) \quad \textbf{(33)}$$

IG - High Infrastructure

Figure 34 shows the global indices for the three alternatives in the elevated infrastructure option for the three modes. As shown in the figure, the MNT has the best global index, followed, in order, by the LRT and BRT modes.

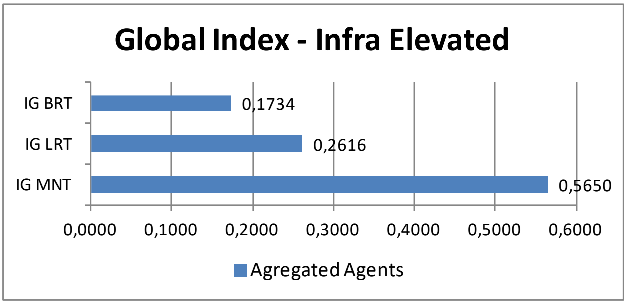

Figure 34 - Global Index and Priority Order of Alternatives - Case Study. Elevated Infrastructure.
Source: Prepared by the author.

IG - Elevated Infrastructure for MNT and at Level for BRT and LRT

As Figure 35 shows, the MNT continues to have the best overall rating in the MNT-only elevated infrastructure option. The performances of the sub-criteria are quantified in Table AIII-4 (Annex III). In this option of installing infrastructures, the Global Index of the MNT has improved and reflects the occurrence of the following facts:

- • The installation at street-level of the infrastructures for the BRT and LRT modes greatly affected two criteria that have high scores according to the preferences given to them by the stakeholders (in aggregate form). These criteria are: Trip Quality (affected sub-criteria: QVSVV, "safety between system and street-road system vehicles" and QVSVM, "average travel speed"); and Environmental Impact (affected sub-criteria: IASO, "road system occupation" and IADV, "division of the street-road system");
- • However, this street-level installation option was positive in reducing the cost of infrastructure for the BRT and LRT modes, but, again, as the preference given by the stakeholders (in aggregate form) to the Infrastructure Cost criterion (CSII) is very low, this positive reduction in cost had little influence on the overall index. This fact suggests that an specific analysis could be done for the criterion Cost with preferences of stakeholders individualized (not aggregated).

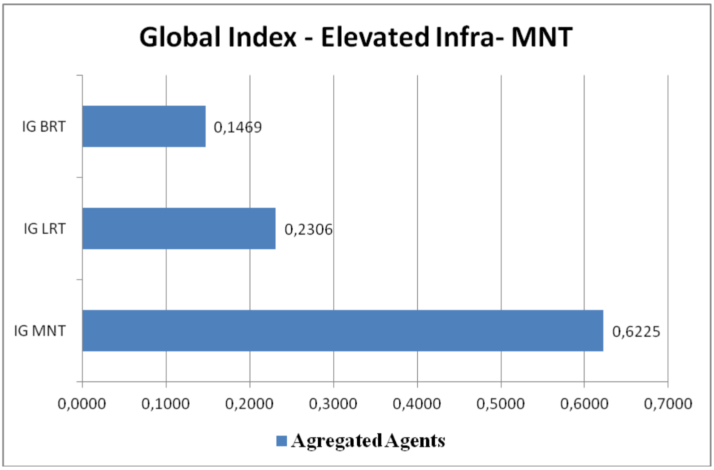

Figure 35 - Global Index and Priority Order of Alternatives - Case Study.
Elevated Infrastructure for the MNT- Street-level for BRT and LRT.
Source: Prepared by the author.

ANALYSIS OF RESULTS AS TO THE PREFERENCES OF STAKEHOLDERS

The analysis that follows is limited to verifying the sensitivity of the order of preference of the alternatives, simulating, among the several possible scenarios, ten of them in which the indices of the criteria in the VPC vector are changed. Scenarios that are simulated:

- VPC with aggregated preferences and Trip Quality (QV), the highest scoring criterion, with a score equal to zero (one case);
- VPCs individualized by stakeholder and higher scores taken to zero (five cases);
- VPC with aggregated preferences and scores exchanged between criteria and VPC with aggregated preferences and author-assigned scores (four cases).

All simulations are performed on an Excel platform (see Annex VI) in which the vectors VPC, VPSC, VPA and equations 31, 32 and 33 are inserted, which calculate the Global Indexes of the three systems alternatives.

Preferences by Criteria – stakeholders aggregated

Figure 36 illustrates the Criteria Priority Vector in Table 20 and shows that the indexes give to the criteria the following order of importance:

- • Trip Quality (QV);
- • Environmental Impact (AI);
- • Energy Efficiency (EE);
- • Costs (CS);

• • And Economic and Financial Feasibility (VEF).

The index attributed to the Trip Quality criterion (QV) indicates that the Decision Maker responsible will need to pay special attention to the User and Consultant agents, direct beneficiaries of this criterion as shown in Figures 30 and 32 when making the final choice of the preferred mode. This criterion accumulates almost 50% of the entire preference score, while all the others added together compute the remaining 50%. The next two most important criteria are Environmental Impact, preference of the Neighbor agent (Figure 29) with 24.2% of the scores and Energy Efficiency, preference of the Operator agent (Figure 28) with 14.5%.

Figure 37 shows what happens with the global index and the order of priority of each modal when the preference of the QV criterion (the highest preference) is set to zero (see Figure 38). As one can see, this action does not affect the order of preferences of the modes.

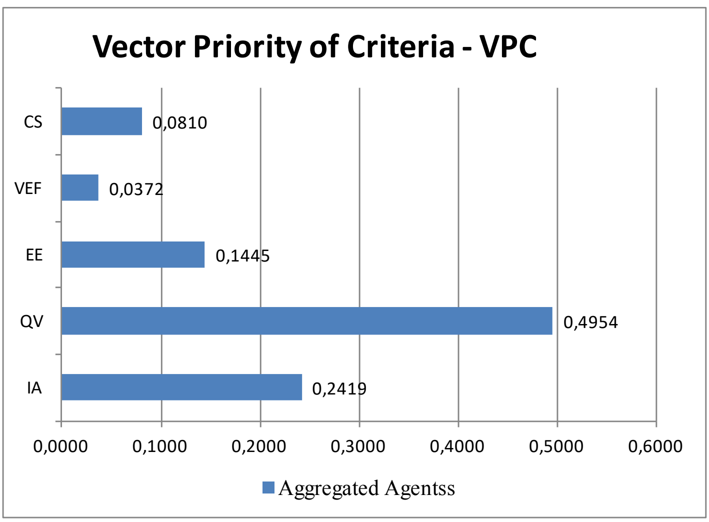

Figure 36 – Vector Priority Of Criteria - Case Study.
Source: Prepared by the author.

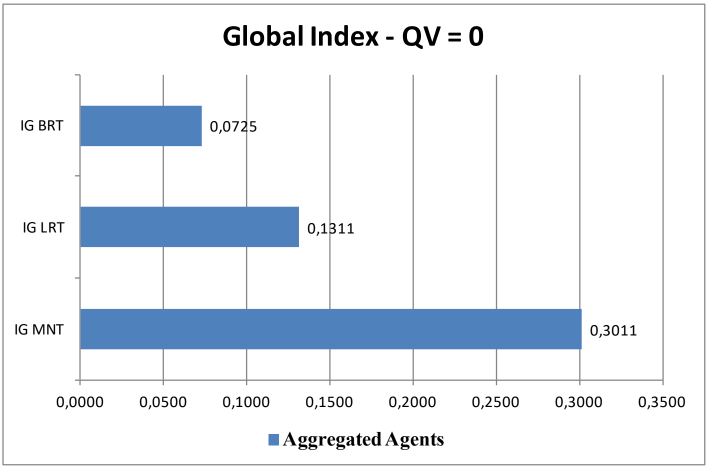

Figure 37 - Global Index (IG) - Aggregated Agents - QV = 0 - Case Study.
Source: Prepared by the author.

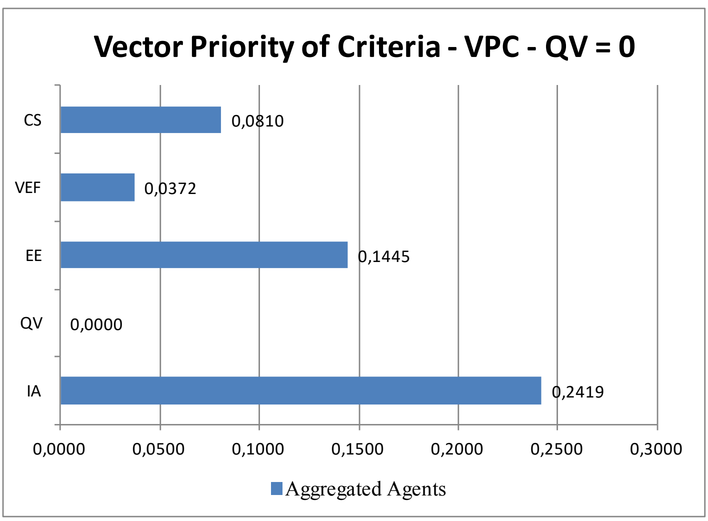

Figure 38 - Criteria Priority Vector (VPC) Aggregate Agents - QV=0 – Case Study.
Source: Prepared by the author.

Preferences by Criteria - stakeholders individualized

Using the same sequence as in the previous item, the VPC vectors individualized by agent and the corresponding global indices are shown when the greatest preferences of each agent are set to zero. Remembering, the objective is to verify what happens with the priority order of the modals when assigning different preferences rates.

Operator Agent

The result shown in Figure 40 does not indicate a change in the order of preference of the alternatives when compared to the preference of the aggregated agents that are assigned to the MNT, LRT and BRT. However, Figure 39 shows that the Operator agent has a different particular preference for the criteria when it is individualized.

The most important criterion for the Operator agent is Energy Efficiency (EE) and not Trip Quality (QV), as shown in Figure 39. This criterion is followed, in terms of priority, given by the Operator Agent, by VEF, CS, QV and IA.

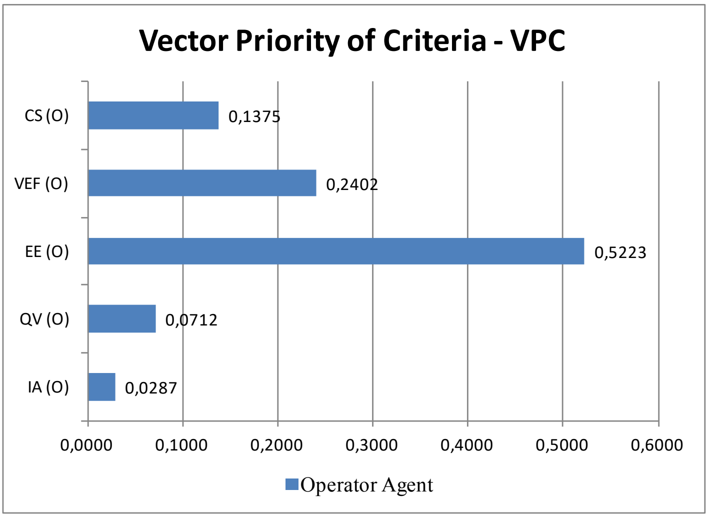

Figure 39 - Criteria Priority Vector (VPC). Operator Agent - Case Study.
Source: Prepared by the author.

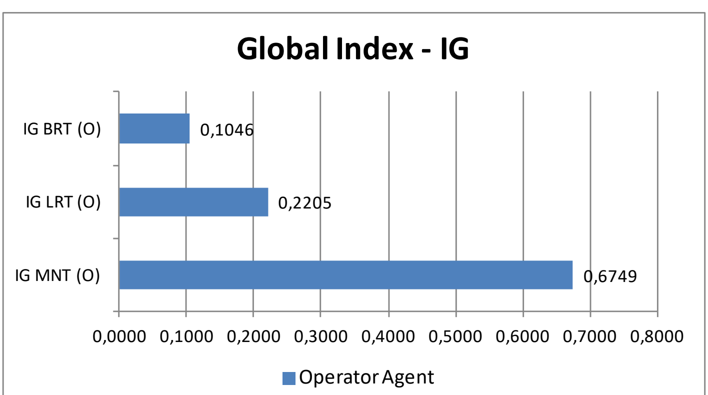

Figure 40 - Global Index of Alternatives. Operator Agent - Case Study.
Source: Prepared by the author.

The Energy Efficiency (EE) criterion score goes beyond 50% in relation to the sum of the others. Thus, this is a criterion that has to be treated with care by Equipment Suppliers in their projects.

Figure 42 shows the effect on the order of alternatives when the EE criterion (Figure 41) is set to zero; the order does not change.

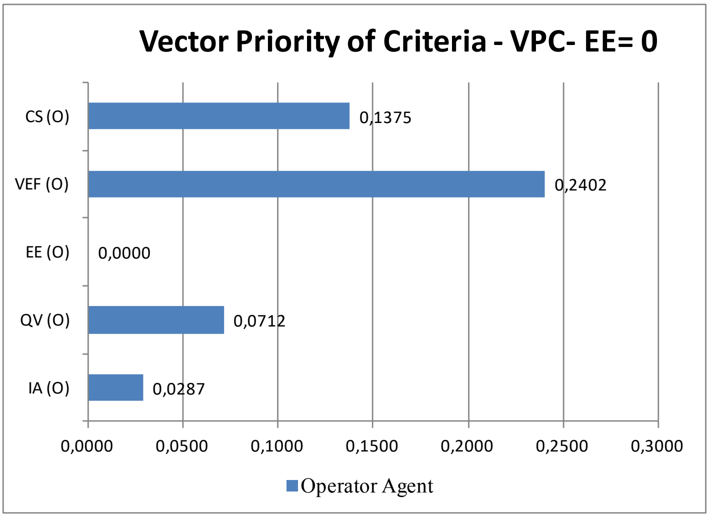

Figure 41 - Criteria Priority Vector (VPC). Operator Agent - EE=0 - Case Study.
Source: Prepared by the author.

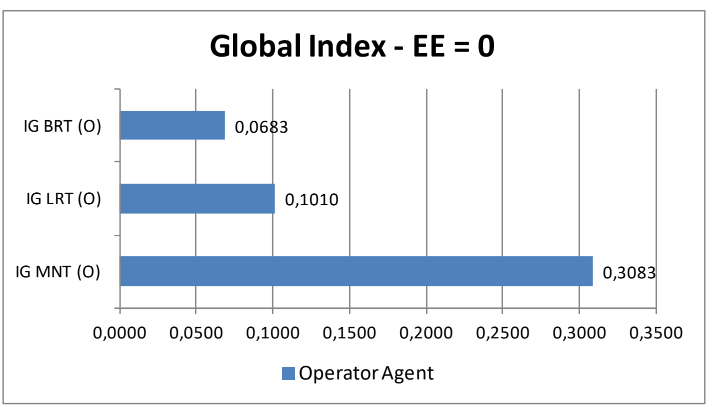

Figure 42 - Global Index (GI). Operator Agent - EE=0 - Case Study.
Source: Prepared by the author.

Neighbor Agent

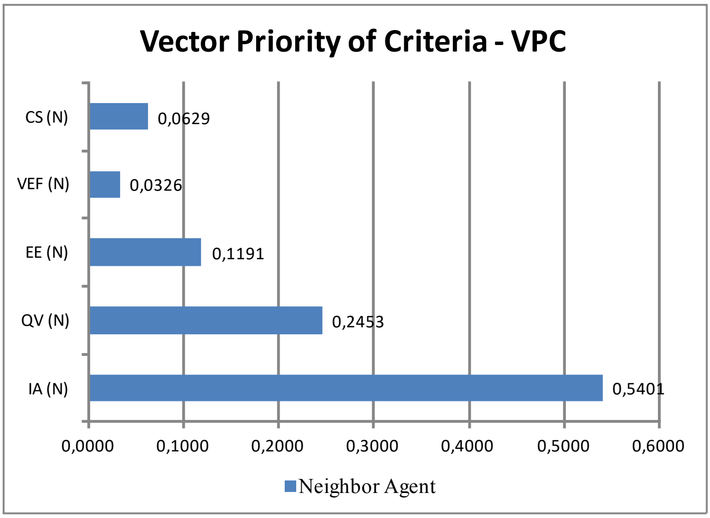

Figure 43 - Criteria Priority Vector (VPC). Neighbor Agent - Case Study.
Source: Prepared by the author.

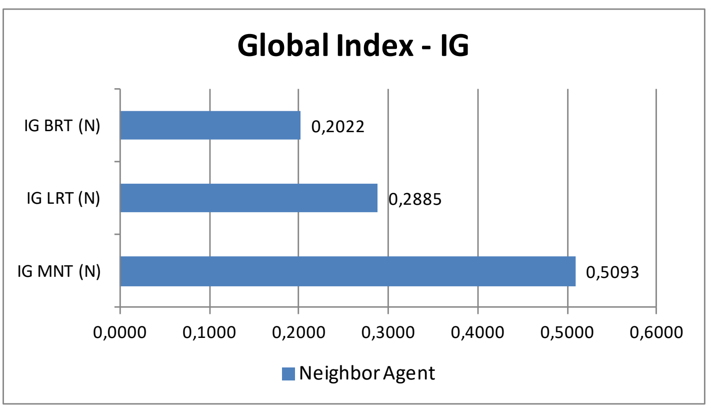

Figure 44 - Global Index of Alternatives. Neighbor Agent - Case Study.
Source: Prepared by the author.

The individualized result shown in Figure 44 does not indicate a change in the order of preference for the alternatives, but the most important criterion for the Neighbor agent is Environmental Impact (IA), followed by QL, EE, VEF and CS (Figure 43).

For the neighboring community the Environmental Impact criterion has a preference score greater than 50% in relation to the other criteria. Intuitively, this preference makes sense, since this is the community that will be living closest to the negative externalities produced by the system (like noise, vehicle pollutions and all the civil infrastructure installed around, for example). This vision of the neighboring community has to be handled with care by the Decision Maker. Reminding, based on the stakeholders' preference survey, individually, AI is not the priority of the Equipment Supplier agent. This is an important message to the Equipment Suppliers as well as for system designers, at pre-design phases, to pay attention on future environmental externalities of the system.

Figure 46 shows the effect on the order of alternatives when criterion IA (Figure 45) is set to zero. In this case, the priority order of the alternatives does not change.

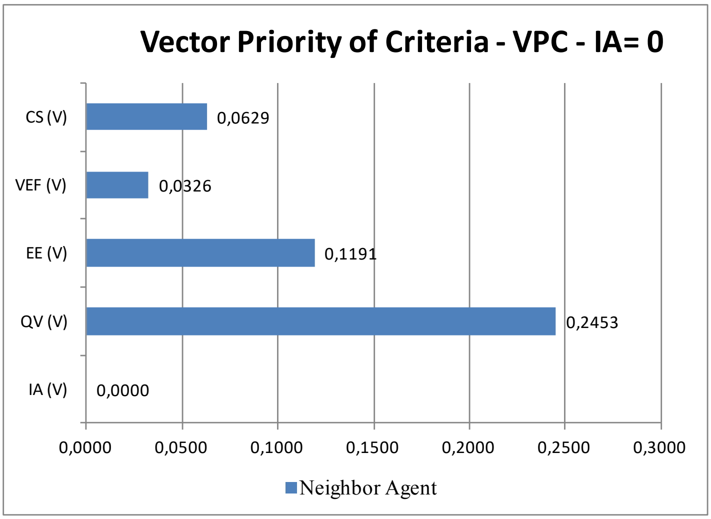

Figure 45 - Criteria Priority Vector (VPC). Neighboring Agent - IA = 0 - Case Study.
Source: Prepared by the author.

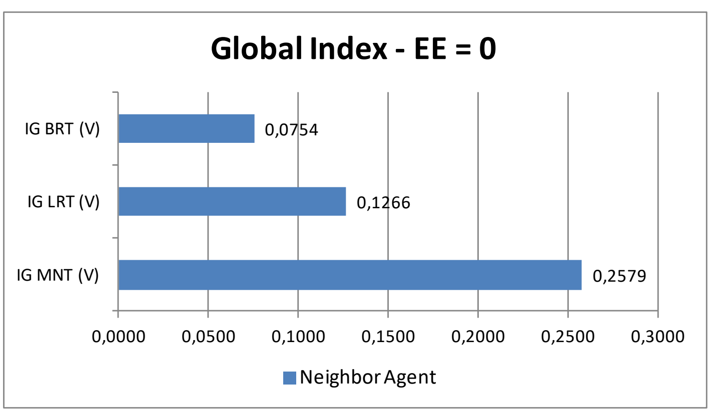

Figure 46 - Global Index of Alternatives. Neighboring Agent - AI = 0 - Case Study.
Source: Prepared by the author.

User Agent

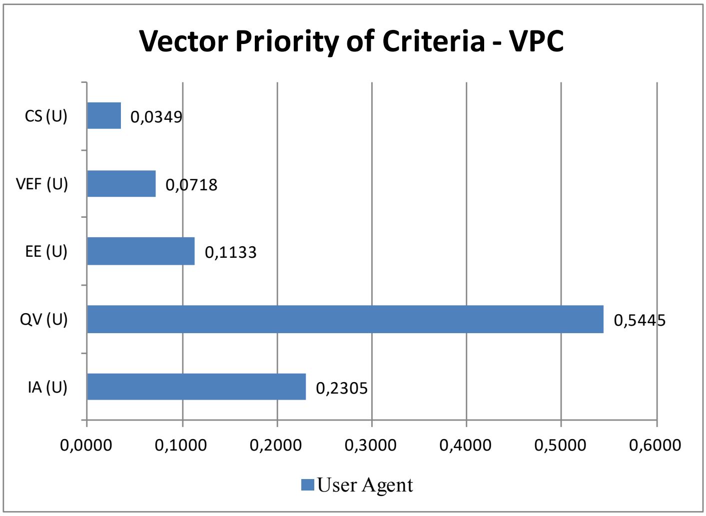

Figure 47 - Criteria Priority Vector (VPC). User Agent - Case Study.
Source: Prepared by the author.

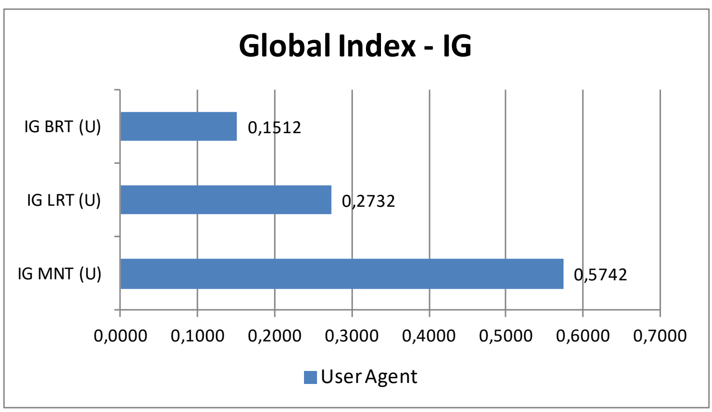

Figure 48 - Global Index of Alternatives. User Agent - Case Study.
Source: Prepared by the author.

Again, the result shown in Figure 48 does not indicate a change in the order of preference for the alternatives. What can be observed is that the User agent is concerned with the Trip Quality (QV) criterion, followed by IA, EE, VEF and CS (Figure 47).

The Trip Quality criterion for the User has a preference score greater than 50% in relation to the other criteria. Intuitively, this preference makes sense since it is very close to the view of the aggregated agents. This fact has to be treated properly by the Decision Maker agent, by the system Operator and by the system and equipment suppliers.

Figure 50 shows the effect on the order of alternatives when the Trip Quality (QV) criterion (Figure 49) is set to zero; the order of alternatives does not change.

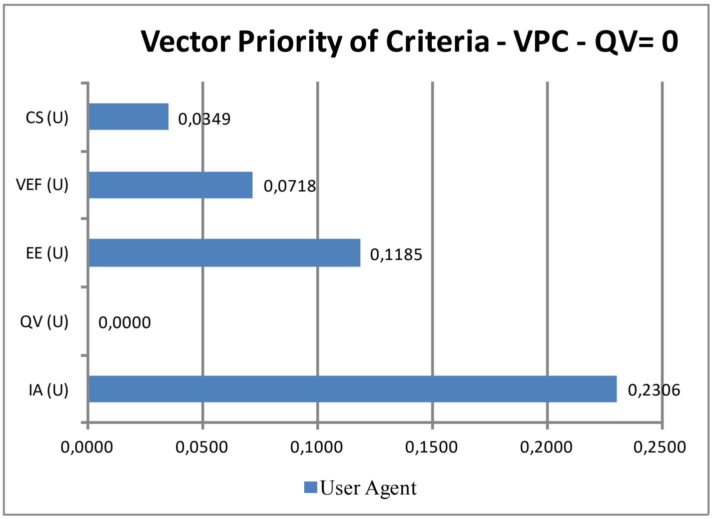

Figure 49 - Criteria Priority Vector (VPC). User Agent - QV = 0 – Case Study.
Source: Prepared by the author.

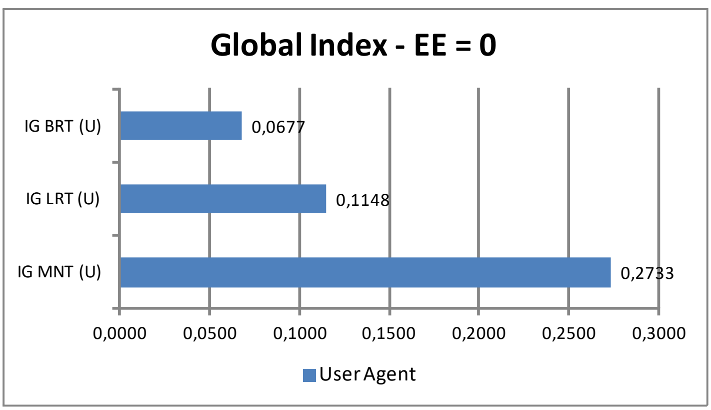

Figure 50 - Global Index of Alternatives. User Agent - QV = 0 - Case Study.
Source: Prepared by the author.

Supplier Agent

Again, the result shown in Figure 52 does not indicate a change in the order of preference for the alternatives. What can be inferred from Figure 51 is that the Supplier agent has a more commercial behavior (Financial and Economic Feasibility - VEF). When asked about equipment and services, its priority lists the criteria in the order: VEF; CS; EE; QV; and IA.

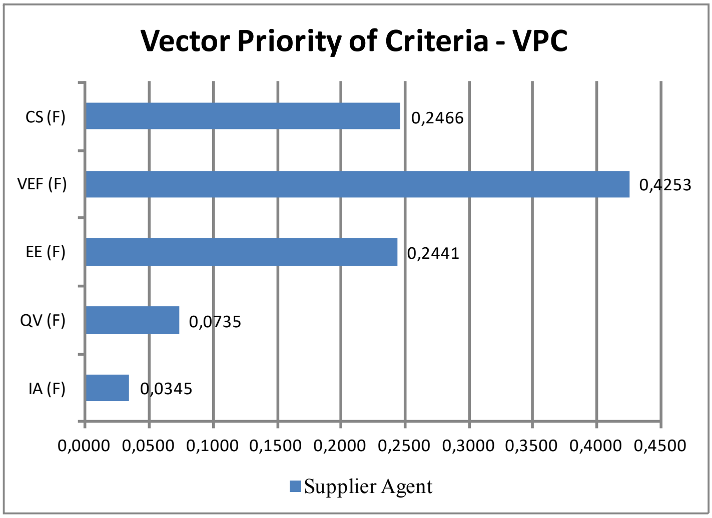

Figure 51 - Criteria Priority Vector (VPC). Supplier Agent - Case Study.
Source: Prepared by the author.

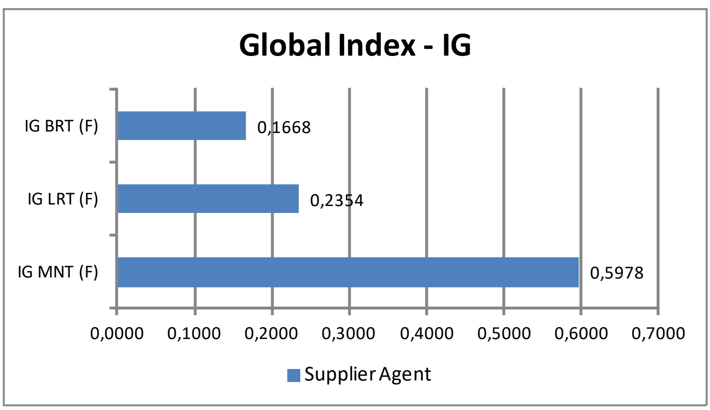

Figure 52 - Global Index of Alternatives. Supplier Agent - Case Study.
Source: Prepared by the author.

Figure 54 shows the effect on the order of alternatives when the FEV criterion (Figure 53) is set to zero; the order of alternatives does not change.

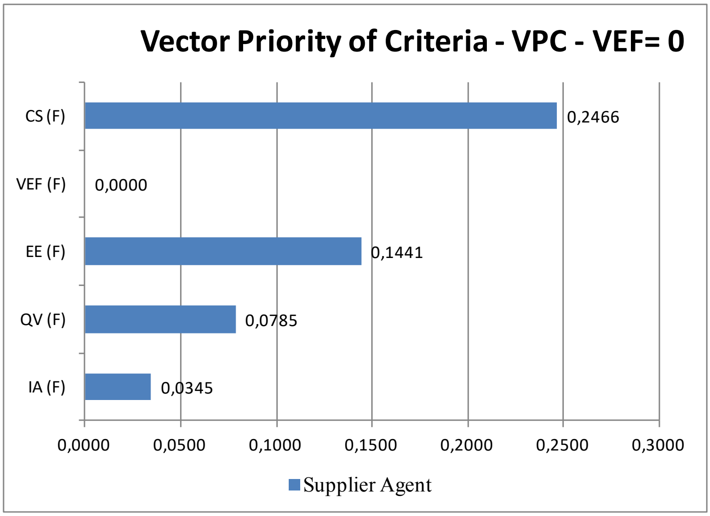

Figure 53 - Criteria Priority Vector (VPC). Supplier Agent - VEF = 0 – Case Study.
Source: Prepared by the author.

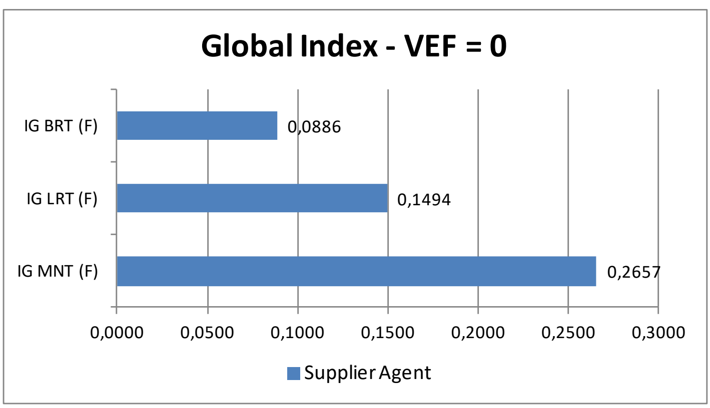

Figure 54 - Global Index of Alternatives. Supplier Agent - VEF = 0 – Case Study.
Source: Prepared by the author.

Consulting Agent

As shown in Figure 56, the Consultant agent, in isolation, also does not change the order of preference for the alternatives; Figure 55 shows this agent giving priority to the Trip Quality criterion, followed by CS, EE, IA and VEF. This view equates the preferences of the User and Operator agents. Figure 58 shows the effect on the order of alternatives when the QV criterion (Figure 57); the alternative priority order does not change.

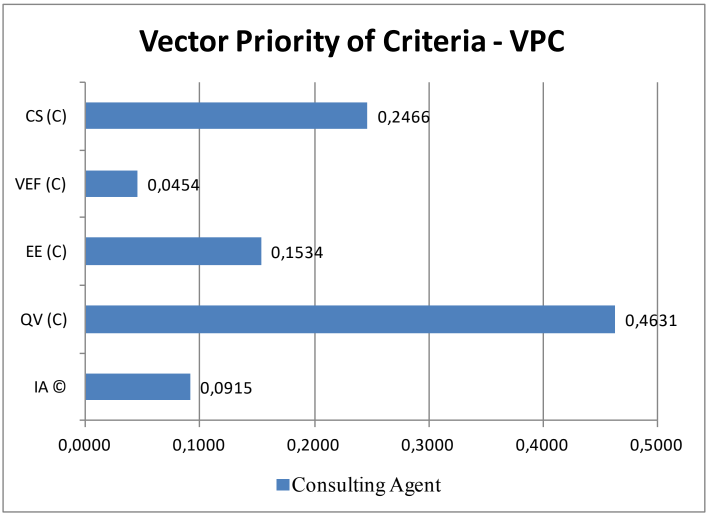

Figure 55 - Criteria Priority Vector (VPC). Consulting Agent - Case Study.
Source: Prepared by the author.

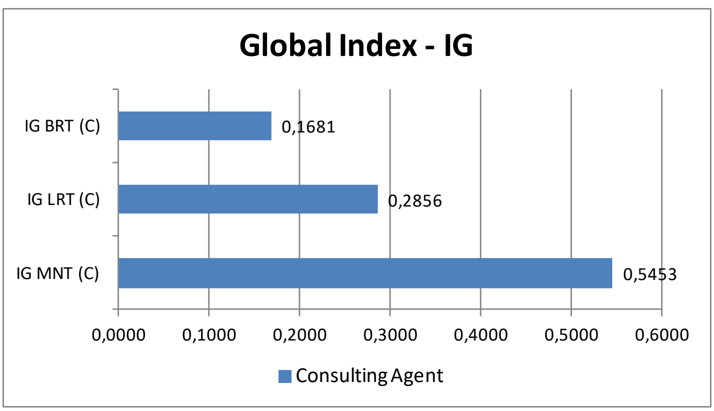

Figure 56 - Global Index of Alternatives. Consulting Agent - Case Study.
Source: Prepared by the author.

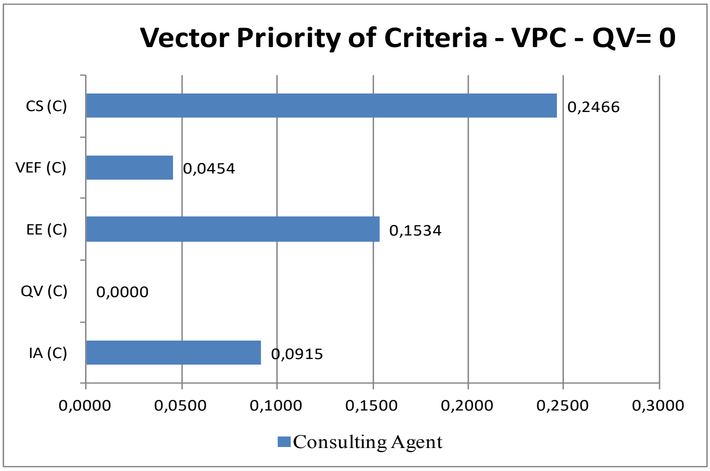

Figure 57 - Criteria Priority Vector (VPC). Consulting Agent - QV = 0 – Case Study.
Source: Prepared by the author.

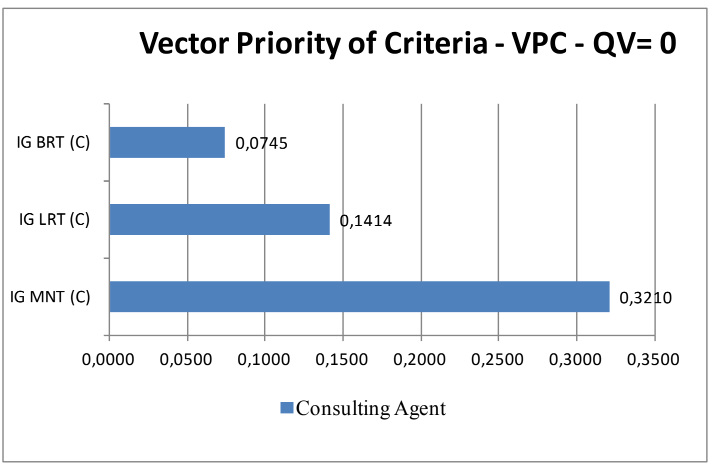

Figure 58 - Global Index of Alternatives. Consulting Agent - QV = 0 – Case Study.
Source: Prepared by the author.

The analysis of the priority order of the alternatives, considering the agent preferences, one by one, not aggregated, indicates that there is robustness in the result obtained in relation to the order of priority of the alternatives when taking the agents' preferences aggregated.

In other words, the conclusion of this limited analysis is that the complete exclusion of the best evaluated criterion, by each class of agent, does not affect the priority sequence of the alternatives.

Preferences for Criteria - Scenarios assigned by the author

The analysis that follows is limited to studying four scenarios attributed by the author, all with infrastructure elevated from the street-road traffic, modifying the preferences attributed by the stakeholders. The new preferences are entered directly into the VPC vector (Table 51). This action will influence the Global Indices (Figures 59 to 62):

- Scenario 1: the score (0.4954) assigned to the Trip Quality criterion (QV) is exchanged with the score (0.0810) assigned to the Cost criterion (CS). In an indirect way, this new preference framework favors Operators and Equipment and Services Suppliers and the result of this simulation will indicate which would be the best rated modal to serve them (instead of the Users);
- Scenario 2: the score (0.4954) assigned to the Quality of Trip (QV) criterion is exchanged with the score (0.2419) assigned to the Environmental Impact (IA) criterion. In an indirect way, this exchange privileges the system's neighbors and, with the same logic, this simulation will indicate which would be the best rated modal to serve them;
- Scenario 3: the score (0.4954) attributed to the Trip Quality criterion (QV) is exchanged with the score (0.1445) attributed to the Energy Efficiency (EE) criterion. Indirectly, this exchange once again privileges the preferences of Operators and Suppliers. With the same logic, this simulation will indicate which would be the best rated modal to serve them in terms of energy efficiency;
- Scenario 4: This scenario was built with preferences given by the author, privileging the criteria of cost and energy efficiency over the others, seeking a situation that could identify the prioritization of the BRT in relation to the MNT.

	Original Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Criteria	VPC				
CS	0,0810	0,4954	0,0810	0,0810	0,8750
VEF	0,0372	0,0372	0,0372	0,0372	0,0250
EE	0,1445	0,1445	0,1445	0,4954	0,0500
QV	0,4954	0,0810	0,2419	0,1445	0,0250
IA	0,2419	0,2419	0,4954	0,2419	0,0250

Table 51 - VPC Vector - Original Scenario - Scenarios 1, 2, 3 and 4.
Source: Prepared by the author.

In the figures that follow, the BRT score is higher than the LRT in Scenario 1 and advances over the LRT AND MNT in Scenario 4. The LRT score is lower than the one for the MNT in all four scenarios.

Scenario 1

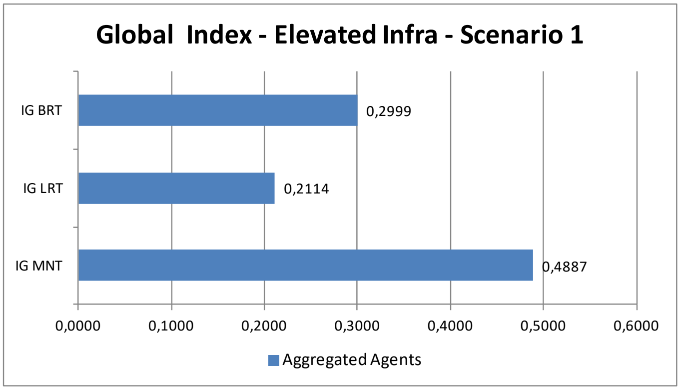

Figure 59 - Global Index - Scenario 1.
Source: Prepared by the author.

Scenario 2

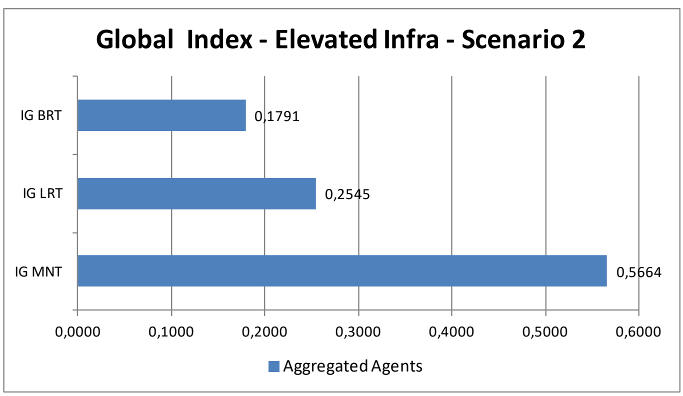

Figure 60 - Global Index - Scenario 2.
Source: Prepared by the author.

Scenario 3

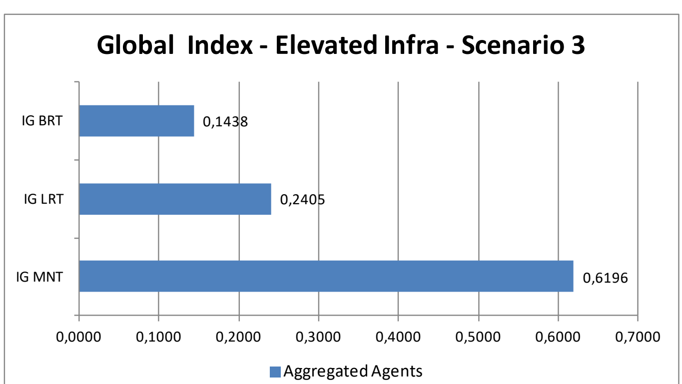

Figure 61 - Global Index - Scenario 3.
Source: Prepared by the author.

Scenario 4

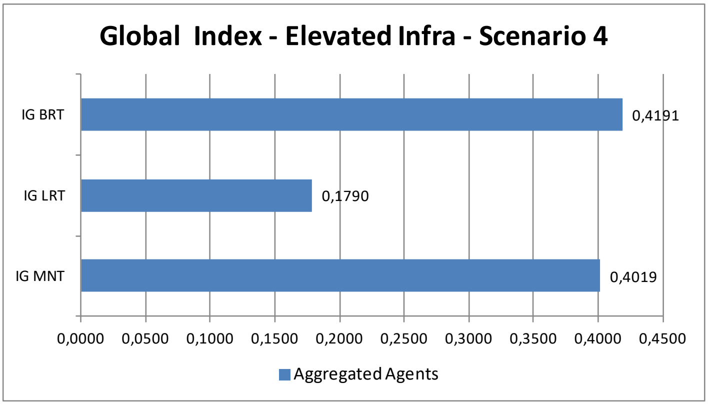

Figure 62 - Global Index - Scenario 4.
Source: Prepared by the author.

RESULTS REGARDING THE PERFORMANCE OF THE ALTERNATIVES

The analysis carried out so far was limited to studying scenarios that reflect changes made in the preferences for the criteria, but the performances of the modals were not changed, that is, no changes were introduced in the preference vector of alternatives (VPA). Changes in the VPA imply in studying technical modifications in the alternatives. This means that such performances (improvements, or modifications, let' say) in the systems under comparison are tasks under responsibility of the manufacturer (Suppliers Agents, herein referred). Follow some relevant comments about this matter.

The Cost criterion for the infrastructure installed at the street level combined with the cost of the vehicles showed that the BRT system is more attractive than the other two modes. This is a fact that alerts manufacturers of LRT and MNT to work towards revising their costs. Costs are important in the analysis of investments and economic and financial viability.

With regard to Energy Efficiency, the MNT vehicles stood out. This can be partly explained by the fact that the vehicles need to be light enough to be able to travel on the raised guide beams. As a consequence, the ratio between passengers load and vehicle weight is relatively better for the MNT.

Focusing on the Trip Quality (QV) criterion, the MNT system was the modal with the best performance. Reminding, the QV associated subcriteria are: high safety integrity level related to accidents between the vehicles of the system and the street-road system (always considering high infrastructure for the three modes); trip punctuality (on schedule); availability of good system performance information to passengers on stations and inside the vehicles; low level noise (internal to the vehicle); and high trip average operating speed.

The LRT showed better performance with respect to universal accessibility. For the Environmental Impact (IA), the best rated modal was the MNT, which presented the best performance in terms of Green House Gas emissions (GEE), area occupied in the road system, aesthetic look, external (to the vehicle) noise, installation time schedule of the infrastructure located at the street-road, and division (separation) of the street-road system.

RESULTS FACE TO THE THEORETICAL REFERENCE FRAMEWORK

The vast majority of attempts at comparisons made between the BRT, VLT and MNT modes, generally found in the bibliography, only reveal the best performance characteristics of each of the modes, that is, those in which each system is more efficient, but not really making more scientific comparisons. It occurs that such type of evaluations results in comparisons made without taking into account a broad base of criteria, as well as the use of adequate configurations of the three modes aiming to solve the same operational and functional requirements of a urban passenger transportation problem.

Comparisons made with the model used in this work were made broadly, based on a common application defined by requirements of a Functional Unit. Based on these requirements, the three modes (Alternatives) were then previously configured before being compared. They were compared against the preferences of decision makers combined with the performance of each of the three modes in relation to a same set of criteria and sub-criteria.

According to the theoretical reference consulted, the three modes under analysis were able to meet, after proper configurations, the requirements of the Functional Unit of the case study. Off course, each one of the modes met the common set off requirements with a greater or lesser degree of adherence to these requirements. In this sense, the decision problem consisted of identifying the most efficient modal, establishing an “order of priority” throughout the so called ”Global Index”.

EFFECTIVENESS AND EFFICIENCY OF THE PROPOSED DECISION MODEL

Within the assumptions of the analysis, the limits of stakeholders’ preferences, the performances of the alternatives and the consistency assessments on the results obtained with the model shown Figure 19, it is considered (author) that the results obtained are quite robust. The model was also suitable for solving the case study proposed, a decision problem fitted within the subject of a complex scenario facing a performance analysis of the modes BRT, LRT and MNT.

The procedure for collecting the preferences data from the decision agents' (stakeholders) has a basic version that was used in this work and is available for future applications. Although effective, the author's recommendation is that it be simplified in order to improve its efficiency.

The procedure for collecting data on the performance of the alternatives was basically bibliographic research, combined with field observations.

And the AHP (Analytic Hierarchy Process) method, which is the basis of the model (Figure 19), has several examples of applications that attest to its effectiveness and efficiency to evaluate and compare systems. The method is well documented and has been subjected, along the time, of improvements done by specialists dedicated to the study of this tool.

Finally, it is noteworthy that the decision for the best modal, ultimately, must always be made by the Decision Maker (TD) stakeholder. Figure 19 shows that, for the analysis of the TD, the Global Indexes and also the individual preferences of the decision agents are presented for the evaluation of the TD. Once having this information in hands, the TD can eventually add other considerations as, citing, for example, political criteria, or assign different importance to the preferences of each class of decision agent.

GLOBAL DISCUSSION

RESULTS REGARDING TO THE GENERAL AND SPECIFIC OBJECTIVES

The results obtained fully met the General Objective, because, within the preestablished limits for the research, the functional and operational performance of the BRT, VLT and MNT technologies were compared and the modals listed in order of priority.

The Specific Objectives were also developed throughout the work, evidenced by the elements of:

- Definition of multiple evaluation criteria and sub-criteria;
- Survey of preferences of decision-makers (Annexes I and II);
- Survey of the performance of the three modes (Annex III);
- Synthesis of preferences and with an additive function;
- Elaboration of the case study.

RESULTS REGARDING TO THE HYPOTHESES

The research produced adequate elements that ratify the pre-established hypotheses. The first hypothesis, about the need to compare modals based on a Functional unit, was validated in the case study. The second hypothesis, about the possibility of elaborating a model - with procedures to process the preferences of decision agents together with alternative performance data, and being able to list the alternatives in order of preference - was also validated in the case study. The third hypothesis, about the possibility of elaborating a model capable of ratifying or rectifying the choice of the MNT modal for Line 15 of the São Paulo Metro, was validated in the case study with a result that ratifies the option within the assumptions and limits established for the study.

RESULTS REGARDING TO THE LIMITS OF THE ANALYSIS

The results obtained in the case study are consistent, within the limits established:

- Pre-defined Functional Unit;
- Subjective Preferences declared by decision-makers for the pre-defined criteria and subcriteria;
- Performances of the alternatives in relation to the criteria and sub-criteria, obtained by the author in the consulted bibliography and in field observations;
- Aggregation of Preferences and Performances via linear additive equations.

LESSONS LEARNED

Some lessons learned during the research are here highlighted.

Procedure to obtain the stakeholders Preferences - Annex I

The procedure for obtaining the subjective preferences of the agents interviewed (Appendix I) can be used in other researches related to the topic herein developed, but a simplification is recommended in order to be more efficient. The stakeholders should answer to simple questionnaires, pre-prepared, with options to make simple notes, such as to answer using numbers, notes like "x", "yes" or "no", etc. Requests for long textual responses should be minimized. Another point that stands out is that face-to-face interviews are more effective, efficient and quickly to obtain answers than issuing questionnaires (forms) for remote filling and return; in this case, it is necessary for the interviewer to carry out good analyzes in order to understand and get coherence data in the material received. During interviews, it was also found that the stakeholder review their preference a lot before finalizing his judgment.

Preferences of Decision Agents - Aggregated and Individualized analysis

Another finding obtained in this research is that the use of aggregated preferences of decision makers should be treated with care because aggregation can mask individual preferences, a fact shown in the case study. The suggestion is that the two results are presented and discussed between the analyst(s) and the decision maker(s), during the final phase of choosing the best alternative.

Planning and workload effort applied in the research

A third point to be highlighted is about the experience gained in the development of the four major blocks of the research which are directly linked with workload (man hour necessary) and time and difficulties to carry out the work. In order, starting with the most complex in the list, they are: (i) definition of the preferences survey form (Annex I) and conducting interviews as well as consolidating the stakeholder preferences (Annex II); (ii) quantification of the performance of the alternatives (Annex III); (iii) Excel platform development made to study and exercise the steps of the decision model (Figure 19) and able to run the VPC, VPSC and VPA vectors and the linear additive equations; (iv) finally, the analysis of all the information collected and the consolidation of the results.

SUGGESTIONS FOR NEW RESEARCHES ALIGNED WITH THIS WORK

Two approaches are suggested for the selection of new researches related to the themes discussed in this work. The first aims to improve the results obtained. The second aims to apply the proposed structure to the decision-making support model in new scenarios. With the first approach, further studies are recommended: improvement on the collection of the preferences of decision makers throughout the set of criteria and sub-criteria; expanding the database for quantifying the performance of alternatives. More specifically, actions as:

- Application of the Preference Survey process to a greater number of agents in the class of system Operators, interviewing urban public transportation professionals;
- Application of the Preference Survey process to decision-makers (using the proposed criteria and sub-criteria form) for collective urban transportation agents in other cities, in addition to the survey carried out in the São Paulo city, targeting to identify if there is a possible preference pattern;
- Addition of a Social Benefits criterion. This criterion was suggested in some interviews. It refers to the quantification of benefits that urban public transportation systems, since providing good quality, can create. Benefits, such as, among others: reduction of private cars on the streets; lower energy consumption due to traffic jams; less environmental pollution; shortening on travel time; improvement on quality of life (lowering people stresses) and cutting medical treatment expenses;
- Improvement on the Sensitivity Analysis of preferences regarding changes in the judgments of the agents interviewed, using the Expert Choice software (Gomes, 2004), which was not used in this research;
- Detailing the assessment of Operating Costs separating them for rolling infrastructure and vehicles. As demonstrated in the quantification of economic and financial feasibility performances, the operating costs of each alternative have a great impact on the calculation of the TRI, TIR and VPL (or NPV) sub-criteria;
- Research the bibliography further, seeking to improve the subjective quantification attributed to the Visual and Aesthetic Impacts of the rolling infrastructure, elevated and at street level.

With the second approach, new researches are suggested applying the proposed model in areas like: Energy Planning, Life Cycle Assessment; Integrated Management of Solid Waste. And, even in Transport, by expanding the scope developed in this work. Follow some suggested topics:

- In Transport, this work focused on the evaluation of three specific modes, but the model can evaluate performances of other modes of interest; the Metro alternative, for example, could be added. The set of criteria and sub-criteria can also be improved as, for example, adding new ones as interconnection points. For new case studies, if carried out in the city of São Paulo, the stakeholders' preferences already available can be used. New modes, if they are introduced, must have their performance calculated on a case-by-case basis (see the example of comparison between the GLT and LRT modes in Annex V).

- Still in Transport, the model can evaluate the case of choosing alternative energy rather than traditional diesel on urban buses, especially in BRT systems. As already described, BRT is a modal used with great success in cities in Brazil and abroad. However, the negative environmental externalities that it produces, due to the use of diesel oil in internal combustion engines, are mentioned in several works that study this modal. Such researches, almost always recommend other fuels, aiming to mitigate the diesel's environmental effects. Cinquina (2008) proposes that projects for future expansions of the BRT in Curitiba should evaluate scenarios that include the Metro, LRT and buses powered by biofuel, as alternatives; she also proposes that representatives of communities interested in transport (stakeholders) are invited in discussion meetings to choose the best solution for the region. Lascala (2011) studied the replacement of diesel by ethanol with additive and has identified, quantified and monetized the main externalities of this replacement in the urban bus fleet in the metropolitan region of São Paulo; for the continuity of his research, the author suggested deep studies of the knowledge of the externalities produced by diesel in relation to the effects of SO_2 gas emissions and the carcinogenic effects caused by the emissions of ultrafine particles and the emissions also present inside the vehicles. In another study, carried out to compare the environmental performance of alternative fuels to diesel for the urban bus fleet in the city of São Paulo, Granville (2014) evaluated the natural gas, biogas, biodiesel, B20 biodiesel (diesel with biodiesel) and sugarcane' diesel; the performance of trolleybuses with electricity was an element that also entered the comparison; the study suggests the continuity of the evaluations with a series of considerations, such as the introduction of improvements in the test protocols studied in the work so that they should consider criteria such as the number of evaluated vehicles (samples), the characteristics of a proper test track (with the addition of ramps), the technologies of electric power generation plants (oil-fired thermoelectric plants? coal?) and the operation and maintenance costs of the different vehicle technologies. The new studies suggested that, for BRT, specifically, there are elements present in the process of choosing the best traction energy (fuel or electric energy) to replace the traditional diesel in BRT systems that characterizes a scenario of a decision making problem in a complex scenario. Just to conclude this BRT focus, it can be said that the multi-criteria model is a proper toll to be herein applied, since there are present multiple stakeholders (users, neighbors, manufacturers and operators) and multiple alternatives (fuel technologies and electric power generation technologies);
- There are other possibilities for application of the decision support model in the transport area such as: infrastructure (selection of road layouts); energy (selection of locations for fuel storage and vehicle supply) and manufacturing (selection of materials with less environmental impact to be used in vehicles and rolling infrastructure);

- Application on Energy Planning: energy generation (selection of locations for installation of generation plants); energy distribution (selection of distribution routes and logistics for transport, storage and distribution); and final utilization (selection of different types of chemical energy - fossil, renewable, alternative ones);
- Life Cycle Assessment: manufacturing (selection of manufacturing sites; mitigations alternatives with focus on environmental emissions; selection of energetic materials (inputs) and energies produced (outputs) that have less impact on the environment); and disposal alternatives (selection of technologies for treatment and disposals of products - solid, liquid, gases, organic);
- Integrated Solid Waste Management: technology (selection of technologies for reuse, treatment and preparation for disposal); collection (selection of collection routes and transportation logistics); and disposal (selection of locations for treatment and disposal).

CONCLUSION

Choosing a viable alternative to solve a given decision problem in collective urban transport is not limited to the study of a modal selection that meet criteria such as energy efficiency or economic and financial engineering. Instead, an analysis of an urban public transportation mode has to be done inserted within the context of a complex decision making process. This means that, before approving investments and deployment, a given alternative to solve the transportation problem should be fully understood throughout a broad systemic assessment involving the study of preferences of stakeholders and performances of alternatives by setting up a broad set of criteria and sub-criteria. When the decision making process has to consider not just one, but several alternatives, the concept of Functional Unit plays an important role. It requires that a previous functional standardization of the alternatives under evaluation should be done, preparing them, in advance, considering system hardware and eventual software configurations. This action will normalize them for post comparisons and ordainments in terms of performances. Well organized, all alternatives will finally be presented to the Decision Making board to help choosing the best one or ones.

The general lines of an evaluation or a system engineering process were presented in this work, developed with bibliographic studies and field researches. Three modes, BRT, LRT and MNT were studied by mean of a case study. The study did not intend to be exhaustive since there are, as listed, still possibilities for researches continuations. It is hoped that the material available, plus the cited references, may be useful to encourage the development of other related studies.

It should be noted that the proposed model employed can be used not only to evaluate performances after the systems are already deployed, but also in their initial phases of project planning, design, manufacturing, test and commissioning. Along execution phases or even in systems already implemented, the model can be used for further evaluations targeting to carry out possible adjustments along their life cycle due to changes in preferences of stakeholders or to technological upgrades on the alternatives.

Finally, overall, it is concluded that the research conducted with the multicriteria decision support (MDA) model combined with the Functional Unit concept targeting to evaluate performances facing of complex scenarios in urban transportation field met the proposed general and specific objectives.

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ANNEX I - PROCEDURE
SURVEY OF PREFERENCES OF DECISION AGENTS

OBJECTIVE

The purpose of this annex is to describe the procedure that was applied by the author in the research of preferences (importance) of the stakeholders (decision agents) by the criteria and sub-criteria selected for the analysis of the research. The survey was conducted between May 2016 and April 2017.

PROCEDURE

Decision making in a Multiple Criteria scenario, stakeholders and Alternatives

Selection and Evaluation of Criteria and Sub-Criteria for Case Study

Research in progress at the Institute of Energy and Environment – IEE/USP

Guilherme Pedroso – 2016 – e-mail: guipedro@uol.com.br

This procedure aims to collect information on the Criteria and Sub-Criteria considered important for an academic study in decision making for the choice of road and rail modals for collective urban transport. The source of this information, whether from individuals or legal entities, will not be mentioned in the study. For the purpose of classifying the material received, the interviewee is requested to indicate (mark an "X") their profile regarding their relationship with public urban transport (use all applicable profiles):

Operator (O) ________; Neighbor of systems (V);________; User (U) ________; System, equipment or service supplier (F) ________; Consultant or Researcher (C) ________; Other (mention) ____ __________________ .

INTRODUCTION

Decision Making that deals with the selection of one among several possible Alternatives to solve a given Problem must (or can, depending on the circumstances) be supported by appropriate methods when the context under study is that of a complex scenario. A complex scenario is one in which, in addition to multiple alternatives, there are also multiple criteria and sub-criteria and multiple decision makers.

Among the support methods there is the so-called Analytic Hierarchy Process

(SAATY, 1980, 1990, 1991). According to this process, the steps that must be followed to identify the alternative that best meets the decision problem requirement's under study are:

a. Clearly define the Decision Problem;

b. Identify the Decision Makers;

c. List the candidate Alternatives to solve the Decision Problem;

d. Define the Relevant Criteria and Sub-criteria that the Alternatives must meet;

e. Design the Decision Problem according to a hierarchical structure that organizes the Decision Makers, the Criteria and Sub-criteria and the Alternatives;

f. Quantify the relative importance between the Relevant Criteria and between the Relevant Sub-Criteria, attributing to them degrees of importance defined by Saaty (1991);

g. Calculate the so-called Global Index (Ibidem, 1991) for each Alternative. It is calculated by adding the weights assigned to Criteria and Sub-Criteria multiplied by the specific parameters of each Alternative. The parameters are calculated by technical analysts. Examples of specific parameters of a particular Alternative (linked to the Criteria and Sub-criteria selected) are: cost (design, manufacturing, installation, operation and maintenance); energy efficiency; environment impacts (amount of CO_2eq gas emissions; noise levels produced outside the vehicle); trip quality (comfort, schedule, noise inside the vehicle, passenger safety);

h. Select the Alternative that has the best Global Index or list them in order of preference so that they can be evaluated by the decision makers in the final selection step.

CASE STUDY

a. Decision Problem:

A group of Decision Makers aims to choose a modal of collective urban passenger transport to equip a medium-capacity linear surface level corridor.

b. Decision Makers:

The Group of Decision Makers is formed by specialists in planning of urban passenger transport systems.

c. Available alternatives:

There are three Solution Alternatives that Decision Makers are working with: Bus Rapid Transit (BRT); Light Rail Vehicle (LRT) and Monorail (MNT).

d. Relevant Criteria and Sub-criteria:

The Decision Makers are working to:

- Assemble the set of Relevant Criteria and Sub-Criteria (item d above);
- And quantify the relative importance between them (item f above).

To this end, they request your contribution to this task, making the following assessments:

ASSESSMENT (1): Selection of Relevant Criteria (1a) and Sub-criteria (1b);

ASSESSMENT (2): Comparison of importance between the pre-selected Criteria;

ASSESSMENT (3a): Comparison of importance between the pre-selected Cost Sub-Criteria;

ASSESSMENT (3b): Comparison of importance between pre-selected Economic and Financial Feasibility Sub-criteria;

ASSESSMENT (3c): Importance Comparison between the pre-selected Trip Quality Sub-criteria;

ASSESSMENT (3d): Comparison of importance between pre-selected Environmental Impacts Sub-criteria.

LEVELS OF IMPORTANCE

The Table **AI-1**, developed by Saaty (1991), defines the Levels of Importance (1, 3, 5, 7 and 9) that should be used to compare, two by two, the Relevant Criteria and Sub-Criteria.

Level 1	Criteria A and B EQUALLY contribute to the achievement of the final Objective of the Decision (the Criteria have equal degree of importance)
Level 3	Criterion A is of SMALL IMPORTANCE in relation to criterion B in achieving the final Objective of the Decision
Level 5	Criterion A is of GRATE IMPORTANCE in relation to criterion B in achieving the final Objective of the Decision
Level 7	Criterion A has VERY GREAT IMPORTANCE (which can be demonstrated in practice) in relation to criterion B, for the attainment of the final Objective of the Decision
Level 9	Criterion A has ABSOLUTE IMPORTANCE (with a high degree of certainty) in relation to criterion B, for the attainment of the final Objective of the Decision

Table AI-1 - Levels of Importance between Criteria and Sub-Criteria.
Source: Prepared by the author based on Saaty (1991).

RELEVANT CRITERIA AND SUB CRITERIA

The Decision Makers Group has previously selected the Criteria and Sub- Criteria considered by them to be Relevant for the analysis of public urban transport systems (Chart AI-1) and requests their contribution with comments and assigning to them the weights (1, 3, 5, 7 and 9) of importance.

O	V	U	F	C	Relevant Criteria	Relevant Subcriteria	O	V	U	F	C
					Cost Of the System	Investment in track infrastructure (INFRA: rolling track; boarding and unboarding stations; electric traction energy distribution system for vehicles)					
						Investment in Vehicles necessary to meet the demand of the Line					
						Energy cost to operate the vehicles over the system life cycle					
						Cost of Operation and Maintenance (O&M) of VEHICLES throughout the system life cycle					
						INFRA's Operation and Maintenance (O&M) cost over the system life cycle					
						Cost for renewing the system (INFRA and VEHICLES) over its life cycle					
					Economic and Financing Feasibility	Return of Investment Time (TRI)					
						Internal Rate of Return (TIR)					
						Net Present Value (VPL, NPV)					
					Energy Efficience	Energy consumed per passenger/km					
					Trip Quality	Safety: accident between vehicles of the Alternative					
						Safety: accident between system (Alternative) vehicles and street road system vehicles					
						Trip time (function of the average speed of the vehicles);					
						Trip adherence to the schedule (function of the Operation Management)					
						Universal Accessibility					
						Quality of the Passenger Information System					
						Internal (to the vehicle) noise level					
					Environmental Impacts	Greenhouse Gas Emissions (GEE, *GHG*) (CO_2eq) throughout the life cycle of the system (vehicle emission);					
						Area of the street-road system occupied by the system (vehicle) rolling infrastructure (INFRA);					
						Aesthetic visual impact of the (vehicle) rolling infrastructure					

					Environmental Impacts	Division of the street-road system caused by the system (vehicle) rolling infrastructure (INFRA)					
					Environmental Impacts	Noise level produced in the environment external to the vehicle (noise caused by the vehicle)					
						Interference (time and installation logistics) in the surroundings area of the system during its implementation					

Chart AI-1 - Form for assigning importance weights to Criteria and Subcriterion.
Source: Prepared by the author.

Evaluation (1) of the Chart AI-1 by the interviewers

1a) Are the Relevant Criteria pre-selected by the Decision Makers SUFFICIENT for the Case Study? (mark your assessment with an "X"):

YES______ NO______

If you checked NO, please indicate other Criteria that you believe that are Relevant to this Case Study:

____

____

____

1b) Are the Relevant Sub-Criteria pre-selected by the Decision Makers SUFFICIENT for the Case Study? (mark your assessment with an "X"):

YES_____ NO______

If you checked NO, please indicate other Sub-Criteria that you believe are Relevant to this Case Study:

____

____

COMPARISON OF IMPORTANCE BETWEEN RELEVANT CRITERIA

Evaluation (2)

Consider the Importance Level Table developed by Saaty (1991) and assign an Importance Level (1 to 9) to compare, **two by two,** the **Pre-Selected Relevant Criteria** by Decision Makers.

Replace the "**X**" with the Level of your choice in the table below:

Note: if you consider that A **is more important** than B, check (**X**).

Note: if you consider that B **is more important** than A, check (**1/X**).

PAIRWISE COMPARISON BETWEEN CRITERIA		LEVEL
A	B	1 a 9
SYSTEM COST	ECON & FINANC FEASIBILITY	X
SYSTEM COST	ENERGY EFICIENCY	X
SYSTEM COST	TRIP QUALITY	X
SYSTEM COST	ENVIRONMENTAL IMPACT	X
ECON & FINANC FEASIBILITY	ENERGY RFFICIENCY	X
ECON & FINANC FEASIBILITY	TRIP QUALIITY	X
ECON & FINANC FEASIBILITY	ENVIRONMENTAL IMPACT	X
ENERGY EFICIÊNCIENCY	TRIP QUALITY	X
ENERGY EFICIÊNCIENCY	ENVIRONMENTAL IMPACT	X
TRIP QUALITY	ENVIRONMENTAL IMPACT	X

Chart AI-2 - Pairwise Comparison between Criteria.
Source: Prepared by the author.

COMPARATION OF IMPORTANCE BETWEEN RELEVANT SUBCRITERIA OF SYSTEM COST

Evaluation (3a)

Consider the Importance Level Table developed by Saaty (1991) and assign an Importance Level (1 to 9) to compare, **two by two ,** the **Relevant System Cost Subcriteria pre-selected** by the Decision Makers.

Replace the X with the Level of your choice in the table below:

Note: if you consider that A **is more important** than B, check (**X**).

Note: if you consider that B **is more important** than A, check (**1/X**).

PAIRWISE COMPARISON BETWEEN SYSTEM COST SUBCRITERIA		LEVEL
A	B	1 a 9
INVESTIMENT IN INFRA	INVESTIMENT IN VEHICLES	X
INVESTIMENT IN INFRA	ENERGY COST TO OPERATE VEHICLES	X
INVESTIMENT IN INFRA	O&M COST FOR VEHICLES	X

INVESTIMENT IN INFRA	O&M COST FOR INFRA	X
INVESTIMENT IN VEHICLE	ENERGY COST TO OPERATE VEHICLES	X
INVESTIMENT IN VEHICLE	O&M COST FOR VEHICLES	X
INVESTIMENT IN VEHICLE	O&M COST FOR INFRA	X
ENERGY COST TO OPERATE VEHICLES	O&M COST FOR VEHICLES	X
ENERGY COST TO OPERATE VEHICLES	O&M COST FOR INFRA	X
O&M COST FOR VEHICLES	O&M COST FOR INFRA	X

Chart AI-3 - Pairwise Comparison between System Cost Subcriteria.
Source: Prepared by the author.

COMPARATION OF IMPORTANCE BETWEEN RELEVANT SUBCRITERIA OF ECONOMIC AND FINANCIAL FEASIBILITY

Evaluation (3b)

Consider the Importance Level Table developed by Saaty (1991) and assign an Importance Level (1 to 9) to compare, **two by two**, the Relevant of **Economic and Financial Feasibility Subcriteria pre-selected** by the Decision Makers.

Replace the **X** with the Level of your choice in the table below:

Note: if you consider that A **is more important** than B, check (**X**).

Note: if you consider that B **is more important** than A, check (**1/X**).

PAIRWISE COMPARISON BETWEEN THE SUBCRITERIA OF ECONOMIC AND FINANCIAL FEASIBILITY SUBCRITERIA		LEVEL
A	B	1 a 9
TIME OF INVESTIMENT RETURN	INTERNAL RATE OF INVESTMENT RETURN	X
TIME OF INVESTIMENT RETURN	NET PRESENT VALUE	X
INTERNAL RATE OF INVESTMENT RETURN	NET PRESENT VALUE	X

Chart AI-4 - Pairwise Comparison between Economical and Financial Feasibility Subcriteria.
Source: Prepared by the author.

COMPARATION OF IMPORTANCE BETWEEN RELEVANT SUBCRITERIA OF TRIP QUALITY

Evaluation (3c)

Consider the Importance Level Table developed by Saaty (1991) and assign an Importance Level (1 to 9) to compare, **two by two**, the Relevant **Trip Quality** Subcriteria pre-selected by the Decision Makers.

Replace the **X** with the Level of your choice in the table below:

Note: if you consider that A **is more important** than B, check (**X**).

Note: if you consider that B **is more important** than A, check (**1/X**).

PAIRWISE COMPARISON BETWEEN TRIP QUALITY SUBCRITERIA		LEVEL
A	B	1 a 9
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES	SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES AND STREET-ROAD VEHICLES	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES	SYSTEM AVERAGE SPEED	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES	QUALITY OF TRIP SCHEDULE	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES	UNIVERSAL ACCESSIBILITY	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES	PASSENGER INFORMATION SYSTEM	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES AND STREET-ROAD VEHICLES	SYSTEM AVERAGE SPEED	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES AND STREET-ROAD VEHICLES	QUALITY OF TRIP SCHEDULE	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES AND STREET-ROAD VEHICLES	UNIVERSAL ACCESSIBILITY	X
SAFETY: ACCIDENTS BETWEEN SYSTEM VEHICLES AND STREET-ROAD VEHICLES	PASSENGER INFORMATION SYSTEM	X
SYSTEM AVERAGE SPEED	QUALITY OF TRIP SCHEDULE	X

SYSTEM AVERAGE SPEED	UNIVERSAL ACCESSIBILITY	X
SYSTEM AVERAGE SPEED	PASSENGER INFORMATION SYSTEM	X
QUALITY OF TRIP SCHEDULE	UNIVERSAL ACCESSIBILITY	X
QUALITY OF TRIP SCHEDULE	PASSENGER INFORMATION SYSTEM	X
UNIVERSAL ACCESSIBILITY	PASSENGER INFORMATION SYSTEM	X

Chart AI-5 - Pairwise Comparison between Trip Quality Subcriteria.
Source: Prepared by the author.

COMPARATION BETWEEN RELEVANT SUBCRITERIA OF ENVIRONMENTAL IMPACTS

Evaluation (3d)

Consider the Importance Level Table developed by Saaty (1991) and assign an Importance Level (1 to 9) to compare, **two by two**, the Relevant **Environmental Impacts Subcriteria pre-selected** by the Decision Makers.

Replace the **X** with the Level of your choice in the table below:

Note: if you consider that A **is more important** than B, check (**X**).

Note: if you consider that B **is more important** than A, check (**1/X**).

PAIRWISE COMPARISON BETWEEN THE SUBCRITERIA OF ENVIRONMENTAL IMPACTS		LEVEL
A	B	1 a 9
CO_2eq EMISSIONS	AREA OCCUPIED IN THE STREET ROAD INFRA	X
CO_2eq EMISSIONS	VISUAL AND AESTHETIC IMPACT IN THE STREET-ROAD INFRA	X
CO_2eq EMISSIONS	DIVISION CAUSED IN THE STREET-ROAD INFRA	X
CO2eq EMISSIONS	NOISE LEVEL EXTERNAL TO THE VEHICLE	X
AREA OCCUPIED IN THE STREET-ROAD INFRA	VISUAL AND AESTHETIC IMPACT IN THE STREET-ROAD INFRA	X
AREA OCCUPIED IN THE STREET-ROAD INFRA	DIVISION CAUSED IN THE STREET-ROAD INFRA	X
AREA OCCUPIED IN THE STREET-ROAD INFRA	NOISE LEVEL EXTERNAL TO THE VEHICLE	X

VISUAL AND AESTHETIC IMPACT IN THE STREET-ROAD INFRA	DIVISION CAUSED IN THE STREET-ROAD INFRA	X
VISUAL AND AESTHETIC IMPACT IN THE STREET-ROAD INFRA	NOISE LEVEL EXTERNAL TO THE VEHICLE	X
DIVISION CAUSED IN THE STREET-ROAD INFRA	NOISE LEVEL EXTERNAL TO THE VEHICLE	X

Chart AI-6 - Pairwise Comparison between Environmental Impacts Subcriteria.
Source: Prepared by the author.

END OF ASSESSMENT

Please send responses to the following email address: guipedro@uol.com.br

REFERENCES

SAATY, TL. **Multicriteria Decision Making**. The Analytic Hierarchy Process. New York: McGraw-Hill, 1980.

______. **How to make a decision**: The Analytic Hierarchy Process. **European Journal of Operation Research.** North-Holland, v. 48, p. 9-26, 1990.

______. **Hierarchical Analysis Method**. Sao Paulo: McGraw-Hill, 1991.

ANNEX II - TABLES - CASE STUDY PREFERENCES OF DECISION AGENTS

OBJECTIVE

The purpose of this Annex is to show, in a consolidated way, the data obtained from opinion polls regarding preferences for the criteria and sub-criteria of the decision problem of this work (case study).

DATA ORGANIZATION

The data are organized in tables.

Criteria

Tables

- Table AII-1: Operator - Criteria (Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impact);
- Table AII-2: Neighbor - Criteria (Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impact);
- Table AII-3: User - Criteria (Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impact);
- Table AII-4: Supplier - Criteria (Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impact);
- Table AII-5: Consultant - Criteria (Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impact).

		CLASS OF STAKEHOLDER: OPERADOR				
N° OF	ID OF	CRITERIA SCORE				
ENTERVIWERS	ENTERVIWERS	SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
1	CREE	8	9	9	7	7
2	DMEB	9	9	9	9	7
3	GPEB	9	9	9	7	5
4	RAEH	7	9	7	9	7
5	MDEH	5	5	9	9	9
6	JFEM	7	7	9	5	3
7	RGEO	9	9	9	5	5
8	RBFM	5,4	5,58	8	5,58	5,4
9	HB	7	9	5	3	1
10	PLFM	5,4	4,8	7,75	4,4	3

CLASS OF STAKEHOLDER: OPERATOR				
CRITERIA SCORE				
SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
7,18	7,64	8,18	6,40	5,24
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
7,00	9,00	9,00	6,29	5,20
MODE	MODE	MODE	MODE	MODE
9,00	9,00	9,00	9,00	7,00
STD DEVATION	STD DEVATION	STD DEVATION	STD DEVATION	STD DEVATION
1,56	1,85	1,32	2,14	2,39

Table AII-1 - Operator - Criteria.
Source: Prepared by the author.

		CLASS OF STAKEHOLDER: NEIGHBOR				
N° OF	ID OF	CRITERIA SCORE				
ENTERVIWERS	ENTERVIWERS	SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
1	JFEM	3	3	3	9	7
2	GPEB	3	1	9	5	9
3	ESEB	1	3	5	5	9
4	CLEB	3	3	3	7	9
5	JCEB	1	1	9	3	9
6	MBEB	7	3	5	9	9
7	RLEB	3	1	1	9	9
8	CAEB	1	1	5	3	9
9	SSEB	3	1	7	5	9
10	ERAH	3	5	5	7	9
11	WSEB	1	1	7	9	7
12	JBEB	7	3	5	7	7
13	AVEB	9	7	1	7	7
14	FREB	3	1	3	9	9
15	EAEB	5	9	9	9	9
16	AMEB	5	7	3	9	7
17	HDEB	1	1	5	7	9
18	DMEB	3	1	7	5	9
19	TYEC	7	5	1	9	3
20	SGEH	7	7	5	5	5
21	TNEH	7	9	7	7	7
22	MDEH	3	9	5	9	9

CLASS OF STAKEHOLDER: NEIGHBOR				
CRITERIA SCORE				
SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
AVERAGE	MÉDIA	MÉDIA	MÉDIA	MÉDIA
3,91	3,73	5,00	7,00	8,00
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
3,00	3,00	5,00	7,00	9,00
MODO	MODO	MODO	MODO	MODO
3,00	1,00	5,00	9,00	9,00
STD DEVIATION	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO
2,45	2,99	2,47	2,05	1,60

Table AII-2 - Neighbor - Criteria.
Source: Prepared by the author.

		CLASS OF STAKEHOLDER: USER				
N° OF	ID OF	CRITERIA SCORE				
ENTERVIWERS	ENTERVIWERS	SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
1	LVFF	2,5	2,5		7	3
2	SMFC	4	4		5	9
3	JPFA	7,5	7,4		9	7,6
4	KHFA	3	2,9		5	3,4
5	SSEB	3	1	5	7	7
6	JEEB	5	1	5	9	3
7	LAEB	5	1	5	9	5
8	GPEB	1	1	1	9	5
9	ESEB	1	5	7	9	7
10	CLEB	7	7	5	7	3
11	JCEB	1	9	1	9	3
12	SBE	3	3	7	9	9
13	DNEB	3	3	7	9	7
14	MBEB	7	3	5	9	7
15	MBFB	2,75	4,25		3	2,75
16	RLEB	3	1	1	9	7
17	CAFB	4,2	4,75		4,3	4,9
18	CAEB	1	1	5	9	7
19	DPFB	4	5		3,75	7
20	FBFB	2,75	3	3	3	2,75
21	WSEB	1	5	5	9	7
22	JBEB	5	3	5	7	7
23	AVEB	9	7	1	7	2
24	FREB	1	1	3	9	5
25	EAEB	3	9	9	7	9
26	AMEB	5	7	3	9	7
27	HDEB	5	7	7	9	7
28	DMEB	5	9	7	9	7
29	SNFA	7	7,6		6,6	5,5
30	JPFA	7,5	7,4		9	7,6
31	KHFA	3	2,9		5	3,4
32	HMFB	5,5	6,3		6	4,9
33	HPFC	6,75	7,75		8,9	7
34	CPEC	5	1		9	9
35	FPFP	2,9	7		5	5,4
36	FPFC	7,8	7,75		9	8,25
37	GLFC	7	6		6,9	8,9
38	JFEM	3	3	3	9	5
39	FIEM	3	5	5	9	7
40	MKEQ	9	8,75	8,75	7,9	6,75
41	JCEG	1	1	5	9	3
42	JBEG	1	1	1	9	5
43	TMFF	5	2,75		5	3,5
44	RAEH	3	5	2	7	7
45	TYEC	7	5	1	9	3
46	SGEH	7	9	5	5	3
47	TNEH	3	3	3	9	7
48	MDEH	7	3	5	9	7
49	RGEO	5	1	5	9	9
50	JMFM	8,75	8,75		9	9
51	IPT1	1	1	2	9	7
52	IPT2	7	5	5	9	8
53	IPT3	5	8	6	6	3
54	IPT4	1	3	6	9	7
55	IPT5	3	2	3	5	4
56	IPT6	3	1	4	9	8
57	HB	5	1	3	9	7
58	PLFM	5,4	4,8	7,75	4,4	3

CLASS OF STAKEHOLDER: USER				
CRITERIA SCORE				
SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
4,32	4,37	4,44	7,62	5,92
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
4,10	4,13	5,00	9,00	7,00
MODE	MODE	MODE	MODE	MODE
3,00	1,00	5,00	9,00	7,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,33	2,73	2,21	1,88	2,10

Table AII-3 - User - Criteria.
Source: Prepared by the author.

		CLASS OF STAKEHOLDER: SERVICE AND EQUIPMENT SUPPLIER				
N° OF	ID OF	CRITERIA SCORE				
ENTERVIWERS	ENTERVIWERS	SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
1	GPEB	9	5	9	9	7
2	ESEB	7	9	7	9	7
3	CLEB	5	9	7	7	5
4	CFEB	3	6		2,75	3
5	JCEB	5	9	5	9	9
6	SBEB	9	9	9	7	7
7	WSEB	7	7	7	7	5
8	JBEB	9	9	7	7	9
9	AVEB	9	9	9	9	7
10	FREB	9	9	7	9	7
11	EAEB	9	9	9	5	7
12	DNEB	7	9	7	7	9
13	HCEB	5	7		3	2,75
14	MBEB	9	9	5	5	5
15	MBFB	2,5	3,75		4	7
16	CAFB	4,2	4,75		4,3	4,9
17	RLEB	7	9	1	3	5
18	CAEB	5	5	5	3	5
19	DPFB	4	5		3,75	7
20	SSEB	7	5	9	7	5
21	FBFB	2,75	3	3	3	2,75
22	CCFB	4,25	3,5	2	3	2
23	ECFB	3,5	4		3	2,75
24	NGFB	3,5	3,7		3,5	3,5
25	SBFX	5,8	5,8		5,8	9
26	RBFX	7,5	8,25		6,4	8,7
27	VLFA	2,75	2,7		2,9	3,4
28	SNFA	7	7,6		6,6	5,5
29	JPFA	7,5	7,4		9	7,6
30	KHFA	3	2,9		5	3,4
31	CPFT	6,25	6,75	5,5	5,4	4,4
32	MKEA	5	5,7	5	7,3	7
33	TYEA	9	5	1	7	3
34	SGEH	9	9	7	5	3
35	TNEH	9	9	5	5	5
36	MDEH	9	7	5	7	5
37	JCEAG	9	3	7	3	5
38	JBEAG	9	9	9	5	9

CLASS OF STAKEHOLDER: SERVICE AND EQUIPMENT SUPPLIER				
CRITERIA SCORE				
SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
6,43	6,60	6,10	5,62	5,62
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
7,00	7,00	7,00	5,20	5,00
MODE	MODE	MODE	MODE	MODE
9,00	9,00	7,00	7,00	7,00
STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION
2,32	2,27	2,44	2,12	2,12

Table AII-4 – Service and Equipment Supplier - Criteria.
Source: Prepared by the author.

		CLASS OF STAKEHOLDER: CONSULTANT AND RESEARCHERS				
N° OF	ID OF	CRITERIA SCORE				
ENTERVIWERS	ENTERVIWERS	SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
1	LVFDTE	2,5	2,5		7	3
2	RGFDTE	2,5	3		3	3
3	BSFDTE	7,5	4		3,5	6
4	TMFDTE	5	2,75		5	3,5
5	AVFDTE	3	2,75		5,5	2,75
6	VAFDTE	3,5	3		4,5	4,25
7	PAFX	7	7	5	5	5
8	RCFX	6	3,5	4	3	4,5
9	SGFH	6,5	2	5	8	5
10	SMFX	4	4		5	9

CLASS OF STAKEHOLDER: CONSULTANT AND RESEARCHERS				
CRITERIA SCORE				
SYSTEM COST	ECON FIN FEASIB	ENERGY EF IC	TRIP QUALITY	ENVIR IMPACT
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
4,75	3,45	4,67	4,95	4,60
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
4,50	3,00	5,00	5,00	4,38
MODE	MODE	MODE	MODE	MODE
2,50	3,00	5,00	5,00	3,00
STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION
1,90	1,40	0,58	1,62	1,87

Table AII-5 – Consultant and Researchers - Criteria.
Source: Prepared by the author.

Figures

- Figure AII-1: Operator - Criteria;
- Figure AII-2: Neighbor - Criteria;
- Figure AII-3: User - Criteria;
- Figure AII-4: Supplier - Criteria;
- Figure AII-5: Consultant - Criteria.

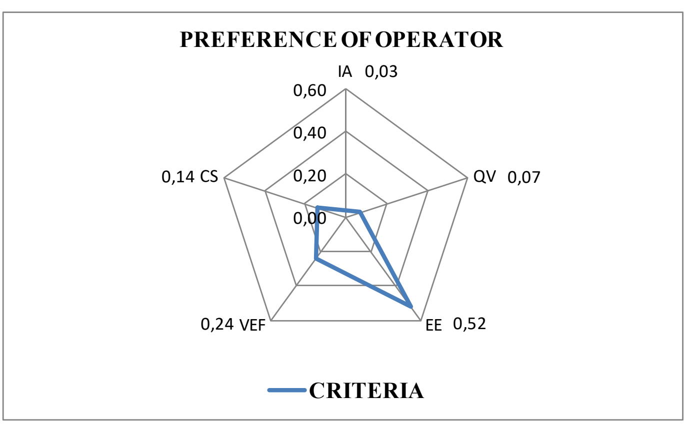

Figure AII-1 - Operator - Criteria.
Source: Prepared by the author.

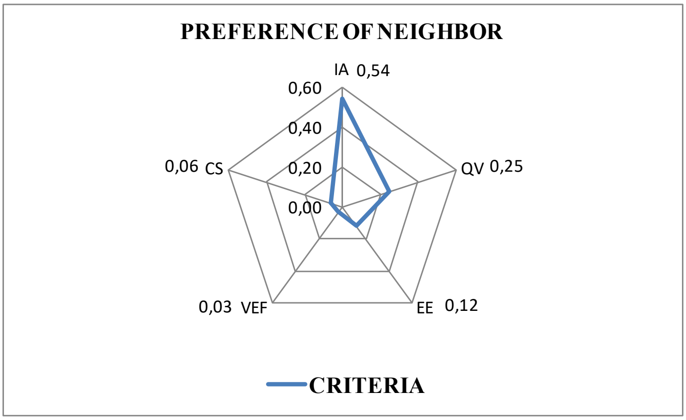

Figure AII-2 - Neighbor - Criteria.
Source: Prepared by the author.

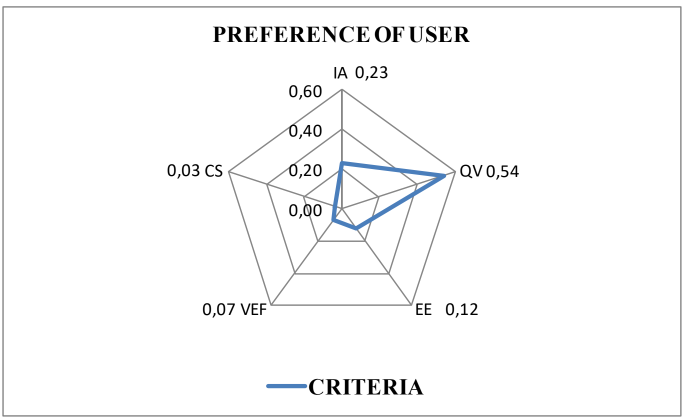

Figure AII-3 - User - Criteria.
Source: Prepared by the author.

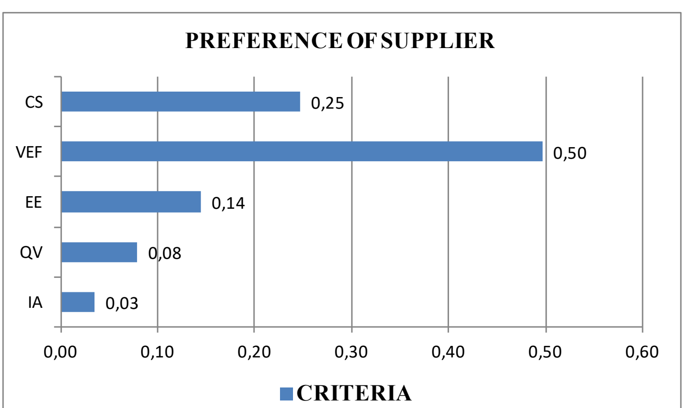

Figure AII-4 - Supplier - Criteria.
Source: Prepared by the author.

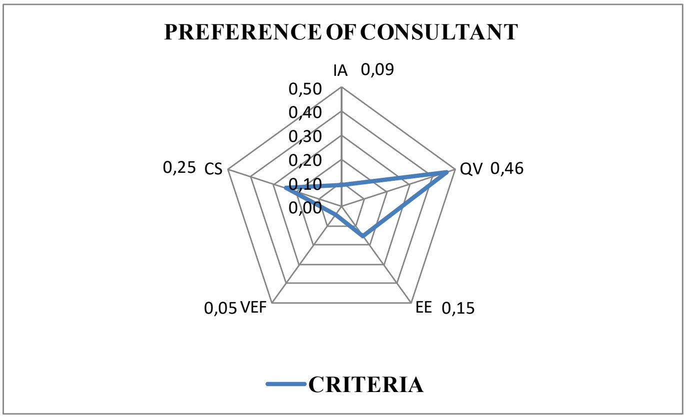

Figure AII-5 - Consultant - Criteria.
Source: Prepared by the author.

Subcriteria

Operator

- Table AII-6: Operator - Subcriteria System Cost;
- Table AII-7: Operator - Sub-criteria Economic and Financial Feasibility;
- Table AII-8: Operator - Subcriteria Trip Quality;
- Table AII-9: Operator - Subcriteria Environmental Impacts.

Table AII-6 - Operator - Subcriteria System Cost.
Source: Prepared by the author.

		CLASS: OPERATOR		
N° OF	ID OFTHE	SUBCRITÉRIO: ECONOMIC AND FINANCING FEASIBILITY RATE		
ENTERVIWERS	ENTERVIWERS	TIME OF INVEST RETURN	INTERNAL RATE OF RETURN	NET PRESENT VALUE
1	CREE	1	1	7
2	DMEB	7	5	9
3	GPEB	5	7	7
4	RAEH	9	7	7
5	MDEH	9	9	9
6	JFEM	7	9	5
7	RGEO	1	7	3
8	RBFM	2,75		3
9	HB	5	9	7
10	PLFM	5,75	5	4

CLASSE: OPERADOR		
SUBCRITÉRIO DE VIABIL ECON E VALORAÇÃO DE IMPORTÂNCIA		
TEMPO DE RET DO INVEST	TAXA INTERNA DE RETORNO	VALOR PRESENTE LÍQUIDO
MEAN	MEAN	MEAN
5,25	6,56	6,10
MEDIAN	MEDIAN	MEDIAN
5,38	7,00	7,00
MODE	MODE	MODE
1,00	7,00	7,00
STD DEVIATION	STD DEVIATION	STD DEVIATION
2,92	2,60	2,23

Table AII-7 - Operator - Subcriteria Economic and Financing Feasibility.
Source: Prepared by the author.

		CLASS: OPERADOR						
N° OF	ID OF	SUBCRITERIA TRIP QUALITY IMPORTANCE RATE						
ENTERVIWERS	ENTERVIWERS	SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
1	CREE	7	7	5	7	3	9	3
2	DMEB	9	9	9	9	5	7	5
3	GPEB	9	7	7	9	5	7	5
4	RAEH	9	9	7	9	7	9	7
5	MDEH	9	9	9	7	7	7	7
6	JFEM	9	9	7	7	5	7	5
7	RGEO	9	9	5	5	7	7	5
8	RBFM	3,7	3	3	3,7	3	3	
9	HB	7	7	9	7	7	5	5
10	PLFM	7,4	7	7,3	6	5	6,5	

CLASS: OPERADOR						
SUBCRITERIA TRIP QUALITY IMPORTANCE RATE						
SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
MEAN	MEAN	MEAN	MEAN	MEAN	MEAN	MEAN
7,91	7,60	6,83	6,97	5,40	6,75	5,25
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
9,00	8,00	7,00	7,00	5,00	7,00	5,00
MODE	MODE	MODE	MODE	MODE	MODE	MODE
9,00	9,00	9,00	7,00	5,00	7,00	5,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
1,72	1,90	1,99	1,76	1,58	1,75	1,28

Table AII-8 - Operator - Subcriteria Trip Quality.
Source: Prepared by the author.

		CLASS: OPERATOR					
N° DE	ID DO	SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE RATE					
ENTREVISTADOS	ENTREVISTADO	GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
1	CREE	7	3	3	3	3	3
2	DMEB	7	7	7	5	9	9
3	GPEB	7	5	5	3	5	1
4	RAEH	7	5	5	5	7	9
5	MDEH	7	5	9	7	7	5
6	JFEM	7	5	5	5	7	1
7	RGEO	5	3	3	5	1	3
8	RBFM	3	4	3,25	3	3,5	
9	HB	5	9	1	7	5	3
10	PLFM	5,L4	6,4	5,25	7	4,3	

CLASS: OPERATOR					
SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE RATE					
GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
6,11	5,24	4,65	5,00	5,18	4,25
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
7,00	5,00	5,00	5,00	5,00	3,00
MODE	MODE	MODE	MODE	MODE	MODE
7,00	5,00	5,00	5,00	7,00	3,00
STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION
1,45	1,84	2,26	1,63	2,37	3,20

Table AII-9 - Operator - Subcriteria Environmental Impacts.
Source: Prepared by the author.

Neighbor

- *Table AII-10: Neighbor - Subcriteria System Cost;*
- *Table AII-11: Neighbor - Subcriteria Economic and Financial Feasibility;*
- *Table AII-12: Neighbor - Subcriteria Trip Quality;*
- *Table AII-13: Neighbor - Subcriteria Environmental Impact.*

		CLASS OF STAKEHOLDER: NEIGHBOR					
N° OF	ID OF	COST SUBCRITERIA : RATE					
ENTERVIWER	ENTERVIWER	INFRA INVESTMENT	VEHICLE INVEST	ENERGY COST FOR VEHICLES	VEHICLE COST	O&M COST FOR INFRA	RENOVATION COST
1	JFEM	5	1	3	3	3	1
2	GPEB	9	5	3	3	7	7
3	ESEB	1	5	3	3	3	1
4	CLEB	9	5	1	1	1	3
5	JCEB	1	1	1	1	1	1
6	MBEB	9	9	5	5	5	5
7	RLEB	3	7	3	7	9	5
8	CAEB	9	1	1	1	1	1
9	SSEB	1	1	1	1	1	1
10	RAEH	5	7	7	7	3	3
11	WSEB	7	9	1	1	1	7
12	JBEB	7	9	7	5	5	7
13	AVEB	3	3	3	3	3	3
14	FREB	7	5	5	1	1	5
15	EAEB	3	3	3	3	3	3
16	AMEB	7	9	7	9	5	5
17	HDEB	3	3	3	3	3	3
18	DMEB	3	3	3	3	3	3
19	TYEC	9	7	5	7	5	9
20	SGEH	7	5	3	3	3	5
21	TNEH	3	1	1	1	1	7
22	MDEH	7	7	5	3	3	5

CLASS OF STAKEHOLDER: NEIGHBOR					
COST SUBCRITERIA : RATE					
INFRA INVESTMENT	VEHICLE INVEST	ENERGY COST FOR VEHICLES	VEHICLE COST	O&M COST FOR INFRA	RENOVATION COST
MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA
5,36	4,82	3,36	3,36	3,18	4,09
MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA
6,00	5,00	3,00	3,00	3,00	4,00
MODO	MODO	MODO	MODO	MODO	MODO
3,00	1,00	3,00	3,00	3,00	3,00
DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO
2,87	2,89	2,01	2,36	2,13	2,37

Table AII-10 - Neighbor - Subcriteria System Cost.
Source: Prepared by the author.

		CLASSE: NEIGHBOR		
N° OF	ID OF	SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
ENTERVIWER	ENTERVIWER	TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
1	JFEM	1	1	1
2	GPEB	1	1	1
3	ESEB	1	1	3
4	CLEB	3	3	5
5	JCEB	1	1	1
6	MBEB	3	3	3
7	RLEB	1	1	1
8	CAEB	1	1	1
9	SSEB	1	1	1
10	RAEH	3	3	1
11	WSEB	1	1	1
12	JBEB	1	1	1
13	AVEB	1	1	1
14	FREB	5	1	1
15	EAEB	9	5	7
16	AMEB	5	5	5
17	HDEB	1	1	1
18	DMEB	1	1	1
19	TYEC	9	5	5
20	SGEH	5	7	1
21	TNEH	9	1	1
22	MDEH	5	5	5

CLASSE: NEIGHBOR		
SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
AVERAGE	AVERAGE	AVERAGE
3,09	2,27	2,18
MEDIAN	MEDIAN	MEDIAN
1,00	1,00	1,00
MODE	MODE	MODE
1,00	1,00	1,00
STD DEVIATION	STD DEVIATION	STD DEVIATION
2,86	1,91	1,92

Table AII-11 - Neighbor - Subcriteria Economic and Financing Feasibility.
Source: Prepared by the author.

		CLASS: NEIGHBOR						
N° OF	ID OF	SUBCRITERIA TRIP QUALITY						
ENTERVIWER	ENTERVIWER	SAFFETY SIST VEHIC	SAFETY SIST VEHIC - STREET ROAD	AVERAGE SPEED	SCHEDULE	UNIVER ACCESSIBILITY	PASSENG INFO SYSTEM	NOISE INTERN TO VEHICLE
1	JFEM	7	5	9	7	5	7	5
2	GPEB	5	5	3	3	3	1	1
3	ESEB	9	9	3	3	5	5	3
4	CLEB	9	9	5	5	3	3	3
5	JCEB	1	1	1	1	1	1	1
6	MBEB	9	7	7	7	5	7	9
7	RLEB	9	9	7	5	1	3	7
8	CAEB	9	9	7	9	7	9	1
9	SSEB	9	9	5	5	7	5	5
10	ERAH	9	9	9	9	9	7	9
11	WSEB	9	9	7	9	7	7	5
12	JBEB	5	5	1	7	7	5	3
13	AVEB	9	9	7	9	9	3	9
14	FREB	9	9	7	7	9	7	5
15	EAEB	9	9	7	9	9	5	3
16	AMEB	7	7	5	7	9	5	7
17	HDEB	9	7	7	9	7	7	7
18	DMEB	9	9	7	9	7	7	9
19	TYEC	9	9	5	7	3	3	1
20	SGEH	9	9	7	5	3	1	3
21	TNEH	1	7	9	5	5	5	7
22	MDEH	7	7	5	5	7	5	9

CLASS: NEIGHBOR						
SUBCRITERIA TRIP QUALITY						
SAFFETY SIST VEHIC	SAFETY SIST VEHIC - STREET ROAD	AVERAGE SPEED	SCHEDULE	UNIVER ACCESSIBILITY	PASSENG INFO SYSTEM	NOISE INTERN TO VEHICLE
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
7,64	7,64	5,91	6,45	5,82	4,91	5,09
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
9,00	9,00	7,00	7,00	7,00	5,00	5,00
MODE	MODE	MODE	MODE	MODE	MODE	MODE
9,00	9,00	7,00	9,00	7,00	7,00	3,00
STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION
2,50	2,08	2,29	2,32	2,59	2,27	2,93

Table AII-12 - Neighbor - Subcriteria Trip Quality.
Source: Prepared by the author.

		CLASS: NEIGHBOR					
N° DE	ID DO	SUBCRITERIA ENVIRONMENTAL IMPOACTS: RATE					
ENTREVISTADOS	ENTREVISTADO	GEE (*GHG*)	AREA OCCUP IN STREET-ROAD	AESTHETIC VISUAL - INFRA	DIVISION OF STREET-ROAD	NOISE EXT TO VEHICLE	STREET-ROAD INTERFER AT INSTALL
1	JFEM	7	5	5	7	7	9
2	GPEB	3	3	7	7	5	9
3	ESEB	9	9	9	9	9	9
4	CLEB	9	9	7	9	9	9
5	JCEB	9	9	9	9	9	9
6	MBEB	9	9	9	9	9	9
7	RLEB	9	5	3	3	9	5
8	CAEB	7	3	9	9	9	9
9	SSEB	9	7	7	7	9	9
10	RAEH	9	9	9	9	9	9
11	WSEB	9	9	7	7	9	9
12	JBEB	9	9	7	7	7	5
13	AVEB	5	7	7	9	9	7
14	FREB	9	5	3	7	9	7
15	EAEB	9	9	9	9	9	9
16	AMEB	7	5	5	7	7	5
17	HDEB	9	7	7	9	9	9
18	DMEB	9	5	5	9	9	5
19	TYEC	3	3	3	3	3	3
20	SGEH	7	5	5	7	9	5
21	TNEH	9	9	9	9	9	9
22	MDEH	9	7	9	9	9	7

CLASS: NEIGHBOR					
SUBCRITERIA ENVIRONMENTAL IMPOACTS: RATE					
GEE (*GHG*)	AREA OCCUP IN STREET-ROAD	AESTHETIC VISUAL - INFRA	DIVISION OF STREET-ROAD	NOISE EXT TO VEHICLE	STREET-ROAD INTERFER AT INSTALL
MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA
7,91	6,73	6,82	7,73	8,27	7,55
MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA
9,00	7,00	7,00	9,00	9,00	9,00
MODO	MODO	MODO	MODO	MODO	MODO
9,00	9,00	9,00	9,00	9,00	9,00
DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO
1,93	2,25	2,13	1,80	1,58	1,97

Table AII-13 - Neighbor - Subcriteria Environmental Impacts.
Source: Prepared by the author.

User

- *Table AII-14: User - Subcriteria System Cost;*
- *Table AII-15: User - Subcriteria Economic and Financial Feasibility;*

- *Table AII-16: User - Subcriteria Trip Quality;*
- *Table AII-17: User - Subcriteria Environmental Impacts.*

		CLASS: USER					
N° OF	ID OF	SUBCRITERIA SYSTEM COST: RATE					
ENTERVIWERS	ENTERVIWERS	INVEST IN INFRA	INVEST IN VEHICLES	ENERGY COST FOR VEÍCULOS	O&M COST FOR VEHICLES	O&M COST FOR INFRA	RENOVATION COSTS
1	LVFDTE	5	5	4,5	5	5	
2	SMFX	9	7	5	5	1	
3	JPFA	5	5	5	5	4,75	
4	KHFA	3,7	3,7	3,3	2,8	3,75	
5	SSEB	1	1	1	1	1	1
6	JEEB	5	5	5	3	3	5
7	LAEB	7	9	7	7	7	5
8	GPEB	7	9	7	7	5	5
9	ESEB	7	7	3	3	3	1
10	CLEB	7	9	7	5	5	3
11	JCEB	9	9	1	1	1	1
12	SBEB	3	3	3	3	3	3
13	DNEB	7	3	3	3	3	3
14	MBEB	5	9	5	5	5	5
15	MBFB	4,75	7	2,75	4,75	4,75	2,75
16	RLEB	3	7	5	7	9	5
17	CAFB	2,9	2,8	4	3,4	3,25	
18	CAEB	9	5	1	1	1	1
19	DPFB	4	4,25	4,5	4	4	6,75
20	FBFB	3,5	3	5	5	3	2,75
21	WSEB	7	9	1	1	1	7
22	JBEB	5	7	7	3	5	5
23	AVEB	3	3	3	3	3	3
24	FREB	1	3	5	1	1	5
25	EAEB	3	3	3	3	3	3
26	AMEB	7	9	7	9	5	5
27	HDEB	7	7	5	5	5	7
28	DMEB	3	3	3	3	3	3
29	SNFA	6,75	6,6	6,75	7	7,25	
30	JPFA	5	5	5	5	4,75	
31	KHFA	3,7	3,7	3,3	2,8	3,75	
32	HMFB	4,75	4,75	5	5,9	4,75	
33	HPFC	6,3	5	5	6,75	4,75	
34	CPEC	9	7	7	5	3	
35	FPFP	6	4,75	3,7	2,75	3	
36	FPFC	7,9	8,25	7,8	7,6	8	
37	GLFC	9	5	5,8	6	6,2	
38	JFEM	5	1	3	3	3	1
39	FIEM	9	9	5	7	5	3
40	MKEQ	5	6,3	4,4	3,75	4,75	2,75
41	JCEAG	1	1	1	1	1	1
42	JBEAG	1	1	1	1	1	1
43	TMFDTE	4	3,75	3,75	3,75	4	
44	RAEH	5	7	5	7	3	3
45	TYEC	9	7	5	7	5	9
46	SGEH	7	5	3	3	3	5
47	TNEH	5	5	7	7	5	9
48	MDEH	3	3	7	5	5	7
49	RGEO	9	9	1	1	1	1
50	JMFM	5	5	4,75	5	5	
51	IPT1	5	7	4	9	8	6
52	IPT2	5	5	5	5	5	7
53	IPT3	5	5	5	5	5	6
54	IPT4	6	8	9	7	5	3
55	IPT5	2	2	3	3	4	4
56	IPT6	7	8	2	2	2	6
57	HB	7	7	5	3	3	5
58	PLFM	4,2	4	4,5	6,5	3,75	5,2

CLASS: USER					
SUBCRITERIA SYSTEM COST: RATE					
INVEST IN INFRA	INVEST IN VEHICLES	ENERGY COST FOR VEÍCULOS	O&M COST FOR VEHICLES	O&M COST FOR INFRA	RENOVATION COSTS
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5,37	5,46	4,38	4,36	3,94	4,12
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
5,00	5,00	4,88	4,88	4,00	4,50
MODE	MODE	MODE	MODE	MODE	MODE
5,00	5,00	5,00	5,00	5,00	5,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,25	2,39	1,92	2,15	1,87	2,22

Table AII-14 - User - Subcriteria System Cost.
Source: Prepared by the author.

		CLASS: USER		
N° OF	ID OF	SUBCRITERIA OF ECONOMIC AND FINANCING FEASIBILITY: RATE		
ENTERVIWERS	ENTERVIWERS	TIME FOR INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
1	LVFDTE	1		
2	SMFX	1		1
3	JPFA	4,75		5
4	KHFA	1		1
5	SSEB	1	1	1
6	JEEB	3	3	3
7	LAEB	1	1	1
8	GPEB	1	1	1
9	ESEB	5	5	5
10	CLEB	5	5	7
11	JCEB	1	1	1
12	SBE	1	1	1
13	DNEB	1	1	1
14	MBEB	3	3	3
15	MBFB	1		1
16	RLEB	1	1	1
17	CAFB	1		1
18	CAEB	1	1	1
19	DPFB	6,75		7
20	FBFB	3	2,75	2,75
21	WSEB	1	1	1
22	JBEB	1	1	1
23	AVEB	1	1	1
24	FREB	5	1	1
25	EAEB	9	5	7
26	AMEB	5	5	5
27	HDEB	1	1	1
28	DMEB	1	1	1
29	SNFA	6,75		7
30	JPFA	4,75		5
31	KHFA	1		1
32	HMFB	3		2,75
33	HPFC	1		1
34	CPEC	1		1
35	FPFP	5		4,75
36	FPFC	7,75		8
37	GLFC	2		1,75
38	JFEM	1	1	1
39	FIEM	3	3	7
40	MKEQ	1	1	1
41	JCEAG	9	3	1
42	JBEAG	1	1	1
43	TMFDTE	5		3
44	RAEH	3	3	1
45	TYEC	9	5	9
46	SGEH	5	7	1
47	TNEH	5	3	5
48	MDEH	1	1	1
49	RGEO	1	1	1
50	JMFM	1		1
51	IPT1	8	9	7
52	IPT2	7	7	7
53	IPT3	8	8	8
54	IPT4	8	6	3
55	IPT5	1	1	2
56	IPT6	3	3	3
57	HB	5	5	5
58	PLFM	5,75	5	4

	CLASS: USER		
	SUBCRITERIA OF ECONOMIC AND FINANCING FEASIBILITY: RATE		
	TIME FOR INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
	AVERAGE	AVERAGE	AVERAGE
	3,28	2,89	2,93
	MEDIAN	MEDIAN	MEDIAN
	2,50	1,88	1,00
	MODE	MODE	MODE
	1,00	1,00	1,00
	STD DEVIATION	STD DEVIATION	STD DEVIATION
	2,67	2,32	2,49

Table AII-15 - User - Subcriteria Economic and Financing Feasibility.
Source: Prepared by the author.

		CLASS: USER						
N° OF	ID OF	SUBCRITERIA TRIP QUALITY: RATE						
ENTERVIWERS	ENTERVIWERS	SYS VEHIC SAFETY	SYS AND STREET-ROAD VEHIC SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIV ACCESSIBILITY	PASS INFO SYSTEM	NOISE INTERN TO VEHIC
1	LVFDTE	9	9	5	5,5	6	4	
2	SMFX	9	7	5	7	5	3	7
3	JPFA	9	8,5	6,75	7,5	7	5,5	
4	KHFA	5,5	4,15	3,3	4,5	4,4	5,25	
5	SSEB	9	9	7	9	7	5	5
6	JEEB	9	9	7	9	5	3	5
7	LAEB	9	9	5	7	9	7	5
8	GPEB	9	7	5	9	5	7	7
9	ESEB	9	9	9	9	7	7	7
10	CLEB	9	9	7	5	3	3	7
11	JCEB	9	9	7	9	9	9	9
12	SBEB	9	9	7	9	7	7	7
13	DNEB	9	9	9	9	7	5	7
14	MBEB	9	9	7	9	5	7	7
15	MBFB	4,5	3,5	6,25	6	2,75	2,75	
16	RLEB	9	9	7	5	1	5	7
17	CAFB	9	9	7,25	8,5	7,25	7,75	
18	CAEB	9	9	7	9	7	9	7
19	DPFB	7	7	3	5,25	5,3	4,75	
20	FBFB	7	7	3	6,25	8	5	
21	WSEB	9	9	7	9	7	5	5
22	JBEB	7	7	3	7	7	7	5
23	AVEB	9	9	7	9	9	7	5
24	FREB	9	9	7	7	9	7	5
25	EAEB	9	9	7	9	9	7	9
26	AMEB	7	7	5	7	9	5	7
27	HDEB	9	7	7	9	7	9	7
28	DMEB	9	9	7	9	7	7	9
29	SNFA	9	9	8	7	7,65	7,15	
30	JPFA	9	8,5	6,75	7,5	7	5,5	
31	KHFA	5,5	4,15	3,3	4,5	4,4	5,25	
32	HMFB	5	6,2	4,8	6,45	5,5	6,35	
33	HPFC	6,8	5,75	6,8	7,4	7,35	6	
34	CPEC	9	9	5	7	5	5	
35	FPFP	5,4	5,35	5,55	4,75	6,2	5,5	
36	FPFC	7,4	8	7	7,55	7,4	8	
37	GLFC	7	5	5	4,85	4,8	4,75	
38	JFEM	7	5	9	7	5	7	5
39	FIEM	9	9	5	7	5	7	
40	MKEQ	6,5	6	6	5	4,5	7,15	
41	JCEAG	9	9	7	9	9	9	7
42	JBEAG	5	7	9	9	9	9	9
43	TMFDTE	5,5	6,5	6	7,5	5,5	5	
44	RAEH	9	9	9	9	7	7	7
45	TYEC	9	9	5	7	3	3	1
46	SGEH	9	9	7	5	5	3	1
47	TNEH	9	7	9	9	9	7	9
48	MDEH	9	9	9	7	7	5	7
49	RGEO	9	5	9	9	9	9	9
50	JMFM	9	9	8	9	9	7,5	
51	IPT1	4	5	8	9	6	7	3
52	IPT2	9	9	9	9	9	8	8
53	IPT3	5	6	6	6	7	6	6
54	IPT4	6	7	8	9	5	4	3
55	IPT5	4	4	3	5	3	5	5
56	IPT6	9	8	6	7	7	8	8
57	HB	9	9	7	7	7	5	5
58	PLFM	7,4	7	7,3	6	5	6,5	

	CLASS: USER						
	SUBCRITERIA TRIP QUALITY: RATE						
	SYS VEHIC SAFETY	SYS AND STREET-ROAD VEHIC SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIV ACCESSIBILITY	PASS INFO SYSTEM	NOISE INTERN TO VEHIC
	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	7,91	7,63	6,52	7,40	6,43	6,11	6,27
	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
	9,00	8,75	7,00	7,20	7,00	6,43	7,00
	MODE	MODE	MODE	MODE	MODE	MODE	MODE
	9,00	9,00	7,00	9,00	7,00	7,00	7,00
	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION	STD DEVIATION
	1,61	1,68	1,71	1,55	1,91	1,72	2,05

Table AII-16 - User - Subcriteria Trip Quality.
Source: Prepared by the author.

		CLASS: USER					
N° OF	ID OF	SUBCRITERIA ENVIRONMENTAL IMPACTS: RATE					
ENTERVIWERS	ENTERVIWERS	GEE (*GHG*)	AREA OCCUP IN STREET-ROAD	AESTHETIC VISUAL IMPACT	DIVISION OF STREET-ROAD	ENVIRONMENTAL NOISE	INTERFER IN STREET-ROAD AT INSTALL
1	LVFDTE	4,5	2	2,5	2,5	3	
2	SMFX	3	3	4	2	3	
3	JPFA	7	5,75	5,75	5,75	5,5	
4	KHFA	3,75	2,75	3,75	4,5	3,75	3,4
5	SSEB	5	5	3	3	5	3
6	JEEB	9	5	7	5	5	5
7	LAEB	7	9	3	5	1	5
8	GPEB	5	3	5	5	5	3
9	ESEB	9	5	7	3	5	3
10	CLEB	5	1	3	7	5	5
11	JCEB	9	9	3	1	1	9
12	SBE	9	5	7	7	9	7
13	DNEB	9	3	3	1	9	3
14	MBEB	5	7	7	5	5	9
15	MBFB	3,5	2,75	5	2,75	3	
16	RLEB	7	1	1	3	7	9
17	CAFB	3	2,9	2,8	2,8	2,9	
18	CAEB	7	3	7	9	9	3
19	DPFB	4	5		3,75	7	7
20	FBFB	5,5	4,25	6	6	5,5	
21	WSEB	9	5	5	5	9	7
22	JBEB	9	5	5	5	5	7
23	AVEB	3	5	1	1	1	1
24	FREB	9	7	7	3	3	1
25	EAEB	9	5	5	3	3	3
26	AMEB	7	5	5	7	7	5
27	HDEB	9	7	5	5	7	7
28	DMEB	9	5	5	3	9	5
29	SNFA	6,75	7,2	6,7	6,8	6,8	
30	JPFA	7	5,75	5,75	5,75	5,5	
31	KHFA	3,75	2,75	3,75	4,5	3,75	3,4
32	HMFB	5	4,4	4,75	3,4	3,9	
33	HPFC	5,4	6	5,4	5,75	4,8	
34	CPEC	9	9	5	3	5	
35	FPFP	6,75	5	2,75	2,75	4,5	
36	FPFC	7,75	8	7,5	7,6	7,6	
37	GLFC	2	4	3,25	3,25	1,2	
38	JFEM	1	3	3	5	5	5
39	FIEM	9	5	5	7	7	
40	MKEQ	4,75	4,75	5	5	5	
41	JCEG	9	9	7	7	1	5
42	JBEG	5	5	7	3	5	7
43	TMFDTE	4,5	3,5	4,75	7	5	
44	RAEH	7	3	3	5	7	5
45	TYEC	3	3	3	3	3	3
46	SGEH	1	3	1	5	5	3
47	TNEH	9	9	7	7	9	9
48	MDEH	7	1	5	9	7	5
49	RGEO	7	5	7	9	1	1
50	JMFM	8	5,4	5	6	5	
51	IPT1	7	5	9	7	8	6
52	IPT2	8	7	5	5	7	7
53	IPT3	1	2	3	3	3	3
54	IPT4	7	9	8	5	4	2
55	IPT5	4	2	3	1	5	3
56	IPT6	9	4	4	7	5	3
57	HB	9	5	5	5	7	7
58	PLFM	5,L4	6,4	5,25	7	4,3	

	CLASS: USER					
	SUBCRITERIA ENVIRONMENTAL IMPACTS: RATE					
	GEE (*GHG*)	AREA OCCUP IN STREET-ROAD	AESTHETIC VISUAL IMPACT	DIVISION OF STREET-ROAD	ENVIRONMENTAL NOISE	INTERFER IN STREET-ROAD AT INSTALL
	MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA	MÉDIA
	6,28	4,84	4,80	4,77	5,09	4,82
	MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA	MEDIANA
	7,00	5,00	5,00	5,00	5,00	5,00
	MODO	MODO	MODO	MODO	MODO	MODO
	9,00	5,00	5,00	5,00	5,00	3,00
	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO	DESVIO PADRÃO
	2,45	2,14	1,83	2,05	2,23	2,30

Table AII-17 - User - Subcriteria Environmental Impacts.
Source: Prepared by the author.

Service and Equipment Supplier

- *Table AII-18: User - Subcriteria System Cost;*
- *Table AII-19: User - Subcriteria Economic and Financial Feasibility;*
- *Table AII-20: User - Subcriteria Trip Quality;*
- *Table AII-21: User - Subcriteria Environmental Impacts.*

		CLASS: SUPPLIER					
N° OF	ID OF	SUBCRITERIA SYSTEM COST: RATE					
ENTERVIWERS	ENTERVIWERS	INFRA INVESTMENT	VEHICLE INVESTMENT	ENERGY COST FOR VEHICLES	VEHICLE O&M COST	INFRA O&M COST	RENOVATION COST
1	GPEB	7	7	7	9	7	9
2	ESEB	5	7	9	9	5	9
3	CLEB	3	9	7	5	5	7
4	CFEB	3	3	3	2,75	2,75	
5	JCEB	9	9	9	7	7	7
6	SBEB	9	9	9	9	9	9
7	WSEB	5	5	7	7	7	7
8	JBEB	9	7	7	9	9	7
9	AVEB	9	9	9	9	9	9
10	FREB	9	9	9	9	9	9
11	EAEB	9	3	3	3	3	3
12	DPFB	4	4,25	4,5	4	4	6,75
13	HCEB	7	6,75	7	6,75	9	
14	MBEB	9	9	9	7	5	7
15	MBFB	3	4,5	3	3,5	2,75	
16	CAFB	2,9	2,8	4	3,4	3,25	
17	RLEB	5	5	1	7	9	9
18	CAEB	3	5	1	5	5	1
19	CAFB	2,9	2,8	4	3,4	3,25	
20	SSEB	9	7	7	5	5	7
21	FBFB	3,5	3	5	5	3	2,75
22	CCFB	2,5	3	2,25	2	2,25	4,5
23	ECFB	5,5	7,5	5,5	3,75	5,4	
24	NGFB	3	3	3	2,75	2,75	
25	SBFX	5,9	5,75	5,9	5,8	6	
26	RBFX	6	6	6,7	5,5	6	
27	VLFA	3,4	3,6	4,3	3,5	3,4	
28	SNFA	6,75	6,6	6,75	7	7,25	
29	JPFA	5	5	5	5	4,75	
30	KHFA	3,7	3,7	3,3	2,8	3,75	
31	CPFT	6,9	7,5	6,15	6,45	5,85	7,25
32	MKEA	5	5	6,4	6,4	6,3	6,75
33	TYEC	9	9	5	5	5	9
34	SGEH	9	7	5	7	7	7
35	TNEH	9	7	7	7	7	9
36	MDEH	7	9	5	5	5	3
37	JCEAG	9	9	9	9	1	5
38	JBEAG	9	9	5	7	7	9

CLASS: SUPPLIER					
SUBCRITERIA SYSTEM COST: RATE					
INFRA INVESTMENT	VEHICLE INVESTMENT	ENERGY COST FOR VEHICLES	VEHICLE O&M COST	INFRA O&M COST	RENOVATION COST
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
6,10	6,15	5,68	5,78	5,47	6,80
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
5,95	6,68	5,70	5,65	5,00	7,00
MODE	MODE	MODE	MODE	MODE	MODE
9,00	9,00	7,00	7,00	5,00	9,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,47	2,25	2,29	2,14	2,20	2,34

Table AII-18 - Supplier - Subcriteria System Cost.
Source: Prepared by the author.

		CLASSE: SUPPLIER		
N° OF	ID OF	SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
ENTERVIWER	ENTERVIWER	TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
1	GPEB	7	7	7
2	ESEB	7	7	9
3	CLEB	7	7	9
4	CFEB	8		9
5	JCEB	5	7	7
6	SBEB	9	7	9
7	WSEB	9	7	9
8	JBEB	9	7	9
9	AVEB	9	9	9
10	FREB	9	9	9
11	EAEB	9	9	9
12	DPFB	6,75		7
13	HCEB	9		8
14	MBEB	9	9	4
15	MBFB	1		1
16	CAFB	1		1
17	RLEB	7	9	3
18	CAEB	5	5	1
19	CAFB	1		1
20	SSEB	5	5	5
21	FBFB	3	2,75	2,75
22	CCFB	4,75	3,5	1,75
23	ECFB	9		7,75
24	NGFB	1		1
25	SBFX	6,75		7
26	RBFX	8		7,75
27	VLFA	3		2,75
28	SNFA	6,75		7
29	JPFA	4,75		5
30	KHFA	1		1
31	CPFT	5,75	7	5,9
32	MKEA	9	8,75	8,75
33	TYEC	9	5	5
34	SGEH	5	7	3
35	TNEH	9	9	3
36	MDEH	1	1	1
37	JCEAG	5	3	7
38	JBEAG	9	7	7

CLASSE: SUPPLIER		
SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
AVERAGE	AVERAGE	AVERAGE
6,14	6,58	5,54
MEDIAN	MEDIAN	MEDIAN
6,88	7,00	7,00
MODE	MODE	MODE
9,00	7,00	9,00
STD DESVIATION	STD DESVIATION	STD DESVIATION
2,88	2,26	3,06

Table AII-19 - Supplier - Subcriteria Economic and Financing Feasibility.
Source: Prepared by the author.

		CLASS: SUPPLIER						
N° OF	ID OF	SUBCRITERIA TRIP QUALITY IMPORTANCE: RATE						
ENTERVIWERS	ENTERVIWERS	SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
1	GPEB	9	9	7	9	5	7	9
2	ESEB	9	9	9	9	7	7	7
3	CLEB	9	9	7	9	5	5	7
4	CFEB	6	7,5	2,85	3	3	2,75	
5	JCEB	9	9	5	5	9	5	5
6	SBEB	9	9	9	9	7	7	7
7	WSEB	9	9	7	9	7	7	5
8	JBEB	7	7	5	7	9	7	7
9	AVEB	9	9	9	9	9	9	7
10	FREB	9	9	7	7	7	5	7
11	EAEB	7	7	5	7	7	5	7
12	DPFB	7	7	3	5,25	5,3	4,75	
13	HCEB	6	4	4	5	5	4	
14	MBEB	9	7	7	7	7	5	7
15	MBFB	7	3,75	8	6	2,75	3	
16	CAFB	9	9	7,25	8,5	7,25	7,75	
17	RLEB	9	9	7	7	3	5	1
18	CAEB	9	9	3	3	3	3	5
19	CAFB	9	9	7,25	8,5	7,25	7,75	
20	SSEB	9	9	7	7	7	7	7
21	FBFB	7	7	3	6,25	8	5	
22	CCFB	9	9	1,75	5,25	2	1,75	
23	ECFB	9	9	7,75	7	9	7	
24	NGFB	9	9	5,2	5,8	5,8	5	
25	SBFX	8,2	7,5	7,5	7	7,45	6,75	
26	RBFX	8,2	8,15	7,75	8	7,85	8,2	
27	VLFA	7,5	8,15	3,75	4,25	5,2	3	
28	SNFA	9	9	8	7	7,65	7,15	
29	JPFA	9	8,5	6,75	7,5	7	5,5	
30	KHFA	5,5	4,15	3,3	4,5	4,4	5,25	
31	CPFT	9	9	7,75	7,7	6,85	6,75	
32	MKEA	6,5	6	6	5	4,5	7,15	
33	TYEC	9	9	5	9	3	3	1
34	SGEH	9	9	7	5	3	5	1
35	TNEH	7	7	5	5	5	9	9
36	MDEH	9	7	3	3	5	5	5
37	JCEAG	7	7	7	9	9	5	7
38	JBEAG	7	7	5	5	5	5	5

CLASS: SUPPLIER						
SUBCRITERIA TRIP QUALITY IMPORTANCE: RATE						
SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
8,18	7,91	5,97	6,62	6,01	5,64	5,80
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
9,00	9,00	7,00	7,00	6,93	5,00	7,00
MODE	MODE	MODE	MODE	MODE	MODE	MODE
9,00	9,00	7,00	7,00	7,00	5,00	7,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
1,12	1,49	1,99	1,86	2,03	1,79	2,38

Table AII-20 - Supplier - Subcriteria Trip Quality.
Source: Prepared by the author.

		CLASS: SUPPLIER					
N° OF	ID OF	SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE: RATE					
ENTERVIWERS	ENTERVIWERS	GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
1	GPEB	5	7	7	5	5	7
2	ESEB	9	1	5	5	7	3
3	CLEB	7	1	1	5	5	5
4	CFEB	3	2,75	3	2,75	3	
5	JCEB	9	1	3	1	5	5
6	SBEB	9	7	7	7	5	7
7	WSEB	5	1	5	9	5	5
8	JBEB	9	7	5	7	7	9
9	AVEB	7	3	1	3	3	7
10	FREB	9	3	5	3	7	1
11	EAEB	7	3	3	1	1	1
12	DPFB	4	5		3,75	7	7
13	HCEB	3	3	7	9	7	7
14	MBEB	5	5	5	7	7	7
15	MBFB	5,5	3	4	5	2,75	
16	CAFB	3	2,9	2,8	2,8	2,9	
17	RLEB	5	5	1	7	3	9
18	CAEB	5	3	5	7	5	3
19	CAFB	3	2,9	2,8	2,8	2,9	
20	SSEB	9	7	5	5	7	7
21	FBFB	5,5	4,25	6	6	5,5	
22	CCFB	3,75	3,5	4,5	2	4,5	
23	ECFB	5	7,5	5,25	5	7,5	
24	NGFB	4	3	3,25	4	4	
25	SBFX	8	7	7,25	7,3	7,7	
26	RBFX	7	6,6	7,5	6	8,2	
27	VLFA	3	2,8	3	2,75	3	
28	SNFA	6,75	7,2	6,7	6,8	6,8	
29	JPFA	7	5,75	5,75	5,75	5,5	
30	KHFA	3,75	2,75	3,75	4,5	3,75	3,4
31	CPFT	5	5	5,75	6	6,25	
32	MKEA	4,75	4,75	5	5	5	
33	TYEC	3	3	3	3	3	3
34	SGEH	3	3	3	5	7	3
35	TNEH	9	9	9	9	5	9
36	MDEH	3	1	1	5	5	3
37	JCEAG	9	9	7	7	1	5
38	JBEAG	7	5	5	5	5	3

CLASS: SUPPLIER					
SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE: RATE					
GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5,76	4,31	4,58	5,08	5,03	5,19
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
5,00	3,25	5,00	5,00	5,00	5,00
MODE	MODE	MODE	MODE	MODE	MODE
9,00	3,00	5,00	5,00	5,00	7,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,20	2,27	2,01	2,08	1,87	2,47

Table AII-21 - Supplier - Subcriteria Environmental Impacts.
Source: Prepared by the author.

Consultant

- *Table AII-22: Consultant - Subcriteria System Cost;*
- *Table AII-23: Consultant - Subcriteria Economic and Financial Feasibility;*
- *Table AII-24: Consultant - Subcriteria Trip Quality;*
- *Table AII-25: Consultant - Subcriteria Environmental Impacts.*

		CLASS: CONSULTANT					
N° OF	ID OF	SUBCRITERIA SYSTEM COST: RATE					
ENTERVIWERS	ENTERVIWERS	INFRA INVESTMENT	VEHICLE INVESTMENT	ENERGY COST FOR VEHICLES	VEHICLE O&M COST	INFRA O&M COST	RENOVATION COST
1	LVFDTE	5	5	4,5	5	5	0
2	RGFDTE	4,5	4	4	5	4	0
3	BSFDTE	6,75	4,5	5	4,5	5	0
4	TMFDTE	4	3,75	3,75	3,75	4	0
5	AVFDTE	4	4,75	5	3	3	0
6	VAFDTE	5,25	4	6,25	5	3	0
7	PAFX	7	6	7	7	7	7
8	RCFX	7	4	3	5	6,5	4
9	SGFH	6	5,5	1	6	3	7,5
10	SMFX	9	7	5	5	1	0

CLASS: CONSULTANT					
SUBCRITERIA SYSTEM COST: RATE					
INFRA INVESTMENT	VEHICLE INVESTMENT	ENERGY COST FOR VEHICLES	VEHICLE O&M COST	INFRA O&M COST	RENOVATION COST
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5,85	4,85	4,45	4,93	4,15	1,85
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
5,63	4,63	4,75	5,00	4,00	0,00
MODE	MODE	MODE	MODE	MODE	MODE
4,00	4,00	5,00	5,00	3,00	0,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
1,60	1,05	1,68	1,09	1,80	3,11

Table AII-22 - Consultant - Subcriteria System Cost.
Source: Prepared by the author.

		CLASSE: CONSULTANT		
N° OF	ID OF	SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
ENTERVIWER	ENTERVIWER	TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
1	LVFDTE	1		
2	RGFDTE	5		4,5
3	BSFDTE	1		2
4	TMFDTE	5		3
5	AVFDTE	5		4,5
6	VAFDTE	9		8
7	PAFX	7	5	3
8	RCFX	5	5	1
9	SGFH	5	8,5	4
10	SMFX	1		1

CLASSE: CONSULTANT		
SUBCRITERIA ECONOMIC AND FINANCE FEASIBILITY		
TIME OF INVEST RETURN	INTERNAL RETURN RATE	NET PRESENT VALUE
AVERAGE	AVERAGE	AVERAGE
4,40	6,17	3,44
MEDIAN	MEDIAN	MEDIAN
5,00	5,00	3,00
MODE	MODE	MODE
5,00	5,00	4,50
STD DESVIATION	STD DESVIATION	STD DESVIATION
2,67	2,02	2,17

Table AII-23 - Consultant - Subcriteria Economic and Financing Feasibility.
Source: Prepared by the author.

		CLASS: CONSULTANT						
N° OF	ID OF	SUBCRITERIA TRIP QUALITY IMPORTANCE: RATE						
ENTERVIWERS	ENTERVIWERS	SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
1	LVFDTE	9	9	5	5,5	6	4	3
2	RGFDTE	8,5	8,5	6,5	7	3	3	5
3	BSFDTE	4,5	7	3	3	8	2,5	5
4	TMFDTE	5,5	6,5	6	7,5	5,5	5	7
5	AVFDTE	8	9	4,5	6,25	2,75	3	7
6	VAFDTE	9	9	5	7	5	4,75	5
7	PAFX	9	9	6	9	7	5	5
8	RCFX	3,5	3	2	3	3	3	
9	SGFH	7	6	3,5	5,5	3	2,5	5
10	SMFX	9	7	5	7	5	3	

CLASS: CONSULTANT						
SUBCRITERIA TRIP QUALITY IMPORTANCE: RATE						
SYS VEH SAFETY	SYS STREET ROAD VEH SAFETY	AVERAGE SPEED	TRIP SCHEDULE	UNIVER ACCESSIBILITY	PASS INFORM SYSTEM	NOISE INTERN TO VEHICLE
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
7,30	7,40	4,65	6,08	4,83	3,58	5,25
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
8,25	7,75	5,00	6,63	5,00	3,00	5,00
MODE	MODE	MODE	MODE	MODE	MODE	MODE
9,00	9,00	5,00	7,00	3,00	3,00	5,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,08	1,94	1,43	1,91	1,86	1,01	1,28

Table AII-24 - Consultant - Subcriteria Trip Quality.
Source: Prepared by the author.

		CLASS: CONSULTANT					
N° OF	ID OF	SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE: RATE					
ENTERVIWERS	ENTERVIWERS	GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
1	LVFDTE	4,5	2	2,5	2,5	3	0
2	RGFDTE	7	4	3	3	3	0
3	BSFDTE	3,5	4	1,5	4	3,5	0
4	TMFDTE	4,5	3,5	4,75	7	5	0
5	AVFDTE	2,5	2,75	3	3	3	0
6	VAFDTE	8	3	2,75	4	2,75	0
7	PAFX	4	5	7	5	4	0
8	RCFX	4,5	3	3	3	2,5	0
9	SGFH	8	6,5	7	3	4	0
10	SMFX	3	3	4	2	3	0

CLASS: CONSULTANT					
SUBCRITERIA ENVIRONMENTAL IMPACTS IMPORTANCE: RATE					
GEE (*GHG*)	AREA OCCUP IN THE STREET ROAD	AESTHETIC VISUAL IMPACT	STREET ROAD DIVISION	ENVIRONMENTAL NOISE	STREET ROAD INSTALL INTERFER
AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
4,95	3,68	3,85	3,65	3,38	0,00
MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN	MEDIAN
4,50	3,25	3,00	3,00	3,00	0,00
MODE	MODE	MODE	MODE	MODE	MODE
4,50	3,00	3,00	3,00	3,00	0,00
STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION	STD DESVIATION
2,01	1,29	1,87	1,45	0,76	0,00

Table AII-25 - Consultant - Subcriteria Environmental Impacts.
Source: Prepared by the author.

ANNEX III - PERFORMANCE
BRT, VLT AND MNT ALTERNATIVES

OBJECTIVE

This Annex shows the objective and subjective estimates of the variables that characterize the performance of the BRT, LRT and MNT modes.

DATA BASE ORGANIZATION

Criteria

The relevant criteria selected for the study are: System Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality; and Environmental Impact. These criteria, with the exception of Energy Efficiency, are broken down into 22 sub-criteria, as described below. The acronym MNT is adopted to designate the Monorail mode.

Subcriteria

System Cost (CS)

- Investment in vehicle rolling infrastructure, comprising: rolling lane; boarding and unboarding stations; vehicles' electric energy distribution and supplying system (CSII);
- Investment in vehicles necessary to meet the seat offer demand of the Line (CSIV);
- Energy cost to operate vehicles over the system's lifetime (CSCE);
- Vehicle operation and maintenance costs throughout the system's useful life (CSOMV);
- Cost of operation and maintenance of the track infrastructure along the lifetime of the system (CSOMI);
- Cost for renewing the system (track and vehicle infrastructure) along the lifetime of the system (CSCR).

Economic and Financial Feasibility (VEF)

- Payback Time (VEFTRI);
- Internal Rate of Return (VEFTIR);
- Net Present Value (VEFVPL).

Energy Efficiency (EE)

Sub-criteria for Energy Efficiency were not defined.

Trip Quality (QV)

- Safety: accidents between the own system vehicles (QVSVS);
- Safety: accident between system vehicles and street-road system vehicles (QVSVV);
- Travel time (as a function of average vehicle speed) (QVVM);
- Trip schedule (function of operation management) (QVPV);
- Universal accessibility (QVAU);
- Passenger Information System (QVSIP);
- Level of noise produced in the vehicle's internal environment (QVRI).

Environmental Impacts (IA)

- Greenhouse Gas Emissions - GHG (CO_2eq) throughout the life of the system
- (Vehicles' emission) (IAGEE);
- Area of the street-road system occupied by the system rolling infrastructure (IASO);
- Visual aesthetic impact of the system rolling infrastructure (IAVE);
- Division of the street-road system caused by the system rolling infrastructure (IADV);
- Noise level produced in the environment external to the vehicle (caused by the
- Vehicle) (IARE);
- Interference (time and logistics) in the surroundings area of the system during its implementation (IATI).

PERFORMANCES

System Cost Criteria

Sub-criteria Investment in Road Infrastructure (CSII)

Elevated Infrastructure for the three modes

Elevated infrastructures are illustrated in Figures AIII-1 to 6.

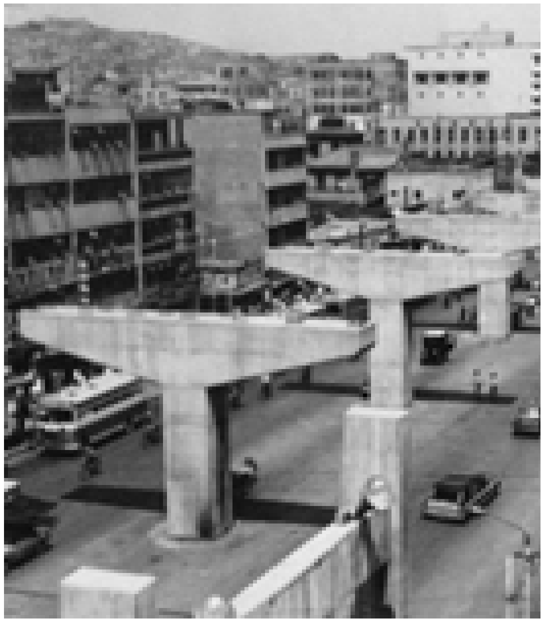

Figure AIII-1 - Example of deck support structure for the BRT.
Source: Minhocão Collection - Elevado Costa e Silva - 1970[1].

Figure AIII-2 - Example of a four lane elevated infrastructure deck for BRT.
Source: Minhocão Collection - Elevado Costa e Silva - 1970[2].

1. Available at: <https://www.google.com.br>.
2. Available at: <https://www.google.com.br>.

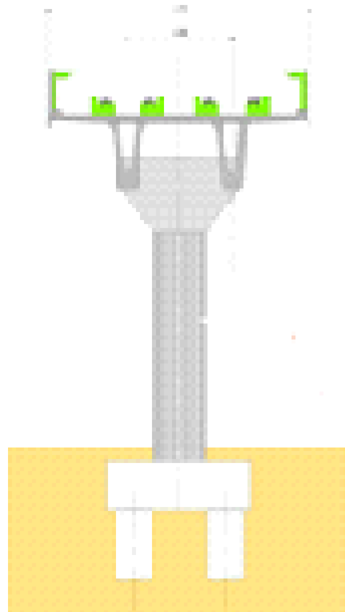

Figure AIII-3 - Support structure example of a two lane Example of a four-street-road lane elevated infrastructure for the BRT elevated LRT deck.
Source: MECCA, 2013.

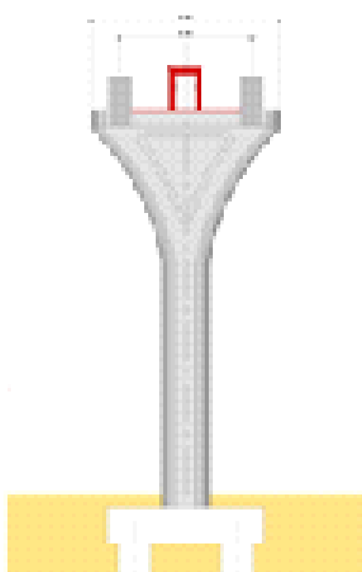

Figure AIII-4 - Supporting Structure Example for a two lane elevated deck for MNT Guide Beams.
Source: MECCA, 2013.

Figure AIII-5 - Example of a two lane elevated deck infrastructure for the LRT.
Source: MECCA, 2013.

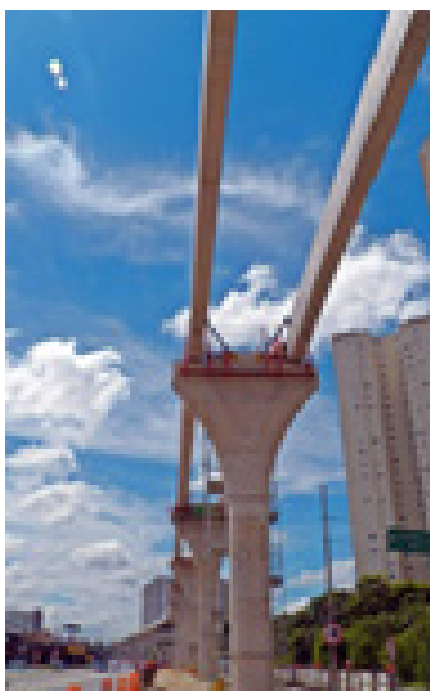

Figure AIII-6 - MNT example of two elevated Guide Beams for MNT on installation phase.
Source: MECCA, 2013.

BRT

Three estimates were made for the cost per km of elevated BRT infrastructure. The first two takes as a reference the construction of the “Elevado Costa e Silva” (former elevated “João Goulart” - “Minhocão”), located in São Paulo. The first reference cost is related to an elevated concrete structure, with four rolling lanes, two for each direction of traffic and has a history of costs.

The cost of this elevated structure was Cr$ 37,000,000 in 1970. This is for 2.73 km, four lanes for tired wheel vehicles, two for each direction of traffic, width from 15.5 to 23.0 meters and 5.5m to 15m meters above the street level. It was built in 14 months, in continuous 24h working days. The job consumed around 300,000 bags (60 kg each) of cement, 60,000 m^3 of concrete and 2,000 t of steel (SILVA, 2016).

The updated dollar cost (from February 1970 to February 2017) of this construction was estimated by the author considering dollars at the time, corrected according to the correction average index (BACEN, 2017; FGV 2017). The updated value was multiplied by a factor of 2.0 (author’s estimate inflation for the period) to compute the elevated deck, in compliance with the requirement of the functional unit of this work. Estimation is US$ 61.4 mi/km (WHEELAN, 2014; SEIFE, 2010; BACEN, 2017).

A second method used to estimate the updated cost of this four-lane elevated infra consisted of updating the original value of the project by the INCC (National Civil Construction Index of Fundação Getúlio Vargas) and applying a factor for the heightening of the deck. Applying the correction by the INCC/FGV from February 1970 to February 2017, the updated value is R$ 237,504,080.37. Multiplied by the same factor 2.0 and using the dollar rate of February 2017 (3.1473), the final estimate is approximately US$ 55.3 mi/km (FGV, 2017; BACEN, 2017).

The third study adopted as reference the project cost for the BRT Expresso Tiradentes. The system is 11.5 km long in elevated infrastructure, two lanes without overtaking at stations, two terminals and 11 stations. Two investments were made, one of R$600 million between 2003 and 2005 and another of R$450 million between 2005 and 2007. In dollars, this investment totalizes US$419 million. Without the costs of the two terminals, the cost per km is on the order of US$ 32.5 mi/km (BACEN, 2017; BASANI, 2017; PlanMob/SP, 2015). The value of the third study is used in this research, plus 20% (author’s estimate) to consider overtaking lanes at stations: US$ 39.0 mi/km.

LRT

The cost for the civil works of the LRT track infrastructure is estimated by adding the cost of the railway infrastructure (LRT Vehicles runs with steel wheels) to the value calculated for the BRT without overtaking lanes, as LRTs typically uses only single lines in both directions. The estimated cost per km for the rail infrastructure made up of rails, Vac Traction voltages sources (not herein considered since they are supplied by others), transformers, rectifiers and electrical energy (Vdc) distribution devices (catenaries) is US$ 26.5 mi/km. This value is an average between the values found in the consulted bibliography: US$ 30 mi/km and US$ 23 mi/km (ALOUCHE, PL, 2012; EMTU - VLT da Baixada Santista, 2013). Then, the total estimate is US$ 59.0 mi/km.

MNT

The cost estimate for the track infrastructure of the Monorail of Line 15 Silver, with 23.8 km of extension is R$ 2.33 billion, base 02/01/2010 (SETMSP, 2013). This value does not compute stations. Updated by the INCC until February 2017, the amount is R$ 3.83 billion. In dollars, using the February 2017 conversion rate (3.1473), the value is US$ 51.1 mi/km.

A Metro' report ("Relatório da Administração", 2016) estimates the total cost of the Monorail of Line 15 for the branch from Vila Prudente to Iguatemi stations at R$ 4.72 billion. The investment has costs for 11 stations (R$ 1.66 billion), the Oratório Depot (R$ 400 million), 27 trains (R$ 1.2 billion), energy systems (R$ 0.15 billion) and telecommunications and auxiliaries systems (R$ 0.15 billion). Isolating only track infrastructure, stations and the energy system and considering about 17.8 km of track lines (15.3 km on the mainline + 2.5 km for the access to the depot), the cost is R$ 2.97 bi or R$ 166.85 bi/km and applying the December 2016 rate (3.383) for conversion into dollars (BACEN, 2017) the cost is US$ 49.32mi / km.

Summary

In summary, the system costs for elevated infrastructure used in this work are: BRT - US$ 39.00mi/km; LRT - US$ 59.00mi/km and MNT - US$ 49.32mi/km.

Infrastructures at street level

BRT

Based on the São Paulo City Hall's Investment Plan 2013-2015 in linear Corridors and Terminals for urban transport (PlanMob/SP 2013-2015, 2013), the updated estimate for September 2017 is US$ 20.75mi/km (average value of corridors for boulevards Celso

Garcia, Belmira Mirim, Vila Natal, Canal do Cocaia, Miguel Yunes, Nossa Senhora do Sabará and Norte Sul).

LRT

It is estimated that the VLT will cost US$ 47.25 mi/km (20.75mi for the rolling lanes plus US$ 26.50mi for the traction power system).

MNT

MNT is not typically installed at street level. For the purpose of comparisons, the already estimated value of US$ 49.32mi/km (elevated installation) will remain.

Summary

In summary, the costs described below for the level infrastructures are used in this work. The BRT, with land expropriations - US$ 20.75mi/km, the LRT, with land expropriations - US$ 47.25mi/km and the MNT continues with the cost of an elevated installation - US$ 49.32mi/km.

Subcriterion Investment in Vehicles (CSIV)

The MNT vehicle fleet estimated by the SP Metro for the VPM to SMT stretch (functional unit definition) is 27 trains. Based on this number of vehicles, the equivalent LRT fleet is estimated to be 68 vehicles. The equivalent BRT fleet was discussed in meetings with SPTrans, in which the number estimated in 146 Super-articulated type of buses.

The estimated investments in vehicles are: BRT Fleet - US$ 100.2mi; LRT Fleet - US$ 432.0mi and MNT Fleet - US$ 321.3mi. Below is the memorial for calculating the fleets and the corresponding costs.

BRT

The average cost of the BRT vehicle (one car) is estimated at US$300,000. This value is based on available information on prices issued in publications by Mercedes-Benz, Scania and VOLVO in Brazil, for projects in Rio de Janeiro, Curitiba and Belo Horizonte cities and also in discussions held (author) with SPTrans (BRTUK, 2015; COSTA, 2014; FREITAS, 2015; LERNER, 2009; PIMENTA, 2014; REIS, 2016, Author's meetings with SPTRans held on Oct 5, 2017).

The price reported by Mercedes-Benz for the Super-articulated model, 23m long, transporting between 170 and 220 passengers, is R$650,000 (base June 2016). Converted into US dollar, about US$ 187 thousand, at a rate of 3.47 R$ per US$ at that time (BACEN, 2017).

The price of the 23m long Mercedes-Benz Super articulated vehicle that SPTrans is using (base September 2017) is R$915,000. With a conversion rate of 3.2 to the dollar, it has a value of US$ 277,300.00 per unit.

The Scania manufacturer informs the prices for the Articulated and Bi-articulated models. The cost of the Articulated, 18.6m long with capacity for 160 passengers, is R$ 560 thousand (base October 2015), or in the order of US$ 146 thousand (rate of 3.83 to the dollar). The Bi-articulated model F360 HA, with a length of 28m and capacity for up to 270 passengers, is worth R$ 750 thousand (base October 2015), in the order of US$ 196 thousand (US$ rate at 3,83).

The Volvo Bi-articulated bus, 28m long and with capacity for up to 250 passengers (in some countries in Europe and Asia they carry around 256 passengers), has a price of R$ 1.0 million (based on October 2014), in the order of US$ 412 thousand (rate of 2.43 R$ to the US$ dollar).

The average price informed by Mercedes for the Mercedes-Benz Super-articulated, by Volvo for the Bi-articulated and by Scania for the F360 HA Bi-articulated is US$ 265 thousand per bus. To harmonize the data collected in the documents consulted, which inform approximate values, the average unit cost of US$ 300 thousand per unit is adopted in this work. This is a value very close to the value reported by SPTrans for the Mercedes-Benz Super-articulated bus that this Authority is using.

Information on the number of passengers and the associated internal comfort are not sufficiently clear in the documents consulted. SPTrans considers, in its load and comfort dimensions, 171 passengers for the Mercedes-Benz Super-articulated, with an internal comfort level of 6 passengers per m^2. Adopting the internal capacity used by SPTrans, the load of the corridor defined by the functional unit and the travel cycle time, the equivalent BRT fleet was estimated at 146 vehicles for the operation of the stretch between Vila Prudente and São Mateus line.

As the legislation of the Municipality of São Paulo (ARTESP, 2004; SMT, 2015) stipulates that buses have to be renewed every 10 years, the total BRT fleet over its useful life (30 years) is 438 buses. At a cost of US$300,000 per unit, the fleet has a total cost of US$100.2 million. The financial analysis, carried out further on, considers the investment of three pavements of US$ 33.4 million, one on date zero of a given project and the next two, every 10 years.

LRT

The cost of the LRT is based on the project of the “Baixada Santista” LRT line. TREMVIA Santos consortium, formed by TTrans and Vossloh has offered 22 vehicles with capacity for 400 passengers each, with a comfort level of 6 passengers per m^2. The price proposed was R$ 284 million, base 08/31/2012. In U$ dollars (conversion rate of 2.03 at the time) the value is US$ 140 million, or US$ 6.36 million each four cars vehicle (BAFERO, 2012).

In order to carry the passenger capacity required by the Functional Unit, equivalent to the MNT fleet of 27 trains, 68 LRT vehicles are needed. The total amount is US$ 432 million.

MNT

The cost of the Monorail train fleet on Line 15 Silver is R$ 1.20 billion - base 01/02/2010 (US$ 642 million considering the rate of 1.87 of the dollar at the time). There are 54 units of 7 cars each, approximately US$ 11.9 million per unit (US$ 1.7 million each car with the capacity to transport 143 passengers with the comfort of 6 passengers per m^2) (SETMSP, 2013). The investment for the acquisition of 27 trains (7 cars each) to meet the Functional Unit passenger load is US$ 322.0 million.

Subcriterion Cost of Energy to operate the vehicles at system lifetime (CSCE)

BRT

Per day, the BRT system carries a total of 329,000 passengers (load adjusted to the vehicle’s capacity) and consumes 86,380 liters of diesel oil. Follow the calculation memory.

Assumptions:

- 250 kW (360 hp) internal combustion engine. This is the type of engine that Mercedes-Benz, Scania and Volvo manufacturers use in their articulated and bi-articulated vehicles: Mercedes-Benz OM-457 LA; Scania SCA-NIA DC13 114 360 and Volvo DH12E (MERCEDES, 2016; SCANIA, 2011; VOLVO, 2016);
- The typical characteristic curve for the 360 hp internal combustion engine (de-clared by VOLVO) is shown in Figure AIII-7;
- Operation with maximum loading (235 passengers, with 6 per m^2);
- Number of vehicles aligned with peak and valley periods of the line.

With the above assumptions, the engine delivers 250 kW of power and consumes about 61.7 liters of diesel oil per hour, according to Equation AIII-1.

- BRT consumption - Liters of diesel oil per hour.

CI = 0.200 (kg/kWh) x 250 (kW) x 1/810 (kg/m^3) x 1000 = 61.7 liters/hour **(AIII-1)**

Calculation memorial:

- CI = C (Energy Equivalence) *P (Power) * 1/ro (MDForum, 2014).

Where:

- CI = Consumption (volume/hour);
- C = Energy equivalence or specific consumption (g/kWh);

Note: for operation between 1400 and 1900 rpm, the average C is 200 g/kWh (Figure AIII-7).

- P = Power (kW); P= 250 kW, for the motor in use;
- ro = Fuel density (kg/m3; multiplied by 1000, the result is obtained in liters).

Note: ro = 810 kg/m^3 for diesel oil.

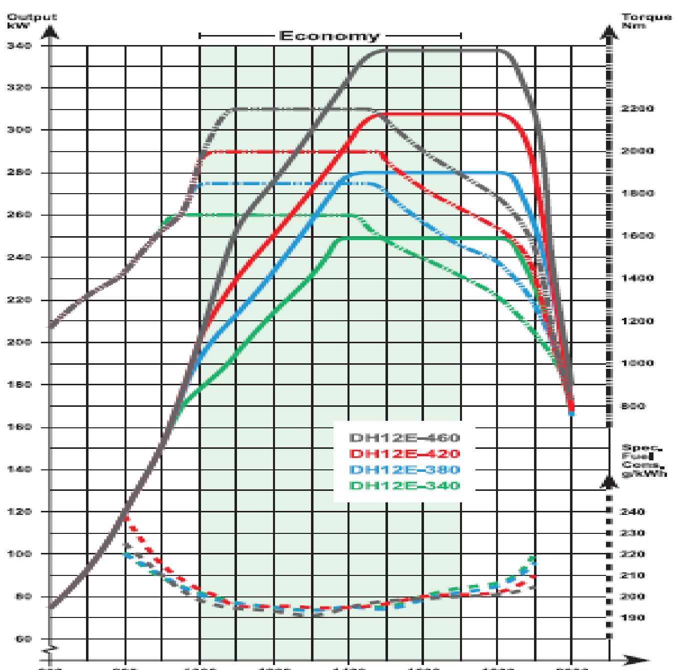

Figure AIII-7 - Characteristic curve of the Volvo DH12E 340 Engine - 250kW.
Source: Volvo (2016).

Adopting the daily operation of 20 hours, 10 hours in peak (100 vehicles operating and 8 in reserve-standby) and 10 hours in valley (40 vehicles operating and the others parked), per day, the system transports a total of 329,000 passengers and consumes 86,380 liters of diesel oil. These numbers may vary and depend on variations in peak and valley ranges and the number of vehicles in reserve.

Calculation memorial

- Daily passenger load at peak period.
    - 100 (vehicles)*(235 passengers/vehicle)*10 (operating hours/day) = 235,000 passengers.
- Daily passenger load at valley period.
    - 40 (vehicles)*(235 passengers/vehicle)*10 (operating hours/day) = 94,000 passengers.
- The daily consumption of the fleet.
    - 146 (vehicles)*10 (operating hours)*61.7 (liters/hour) = 90,082 liters.
- Total fuel used by the fleet over 30 years of operation is calculated using Equations AIII-2 and AIII-3.
- BRT energy consumption over its 30-year useful life (diesel).

90,082 * 300 * 30 = 810,738,000 liters of diesel oil **(AIII-2)**

In Mega joules, the value in liters is multiplied by 35.86 (TÁVORA, 1975):

- Energy consumption of the BRT over its 30-year useful life (Tj).

810,738,000 * 35.86 = 27,878,281,200 Mj = 29.07 Tj **(AIII-3)**

This is the amount of energy used in the study of the Energy Efficiency (EE) criterion.

The cost of energy for the BRT to operate 30 years is (liters of diesel oil) is calculated using Equation AIII-4.

Cost of energy consumed by BRT vehicles over their 30-year lifespan:

810,738,000 * BRL 2,936 per liter (ANP, 2017) = BRL 2,380,326,768.00 = US$ 704,238,688.76 (conversion rate adopted by the author: 3.38: BACEN (2017) JAN/2017) **(AIII-4)**

Note: The Subcriterion Cost of Energy to operate BRT vehicles, over the useful life of the Functional Unit, is not used in the study of the criterion of Economic and Financial Feasibility because this amount is already included in the variable costs of the Subcriterion Operating Cost (CSOMV ; CSOMI).

Note: The maximum daily transport capacity defined by the functional unit at 340,000 passengers can be met by adjusting the number of vehicles allocated as “operational reserve” (or in standby).

LRT

Daily, the LRT system carries a total of 336,000 (load adjusted to the vehicle's capacity) passengers and consumes 504,336 kWh of electrical energy. Follows the calculation memory; it is observed that these numbers can vary and depend on variations in the peak and valley intervals and the amount of vehicles in "operational reserve" (or standby).

Assumptions:

- Average commercial speed of 25 km/h (ALOUCHE, 2012; EMTU, 2013), each VLT vehicle cycles 25.9 km of the functional unit in one hour;
- Daily operation of 20 hours, 10 hours peak (58 vehicles operating and 10 in reserve) and 10 hours in valley (26 vehicles operating and the others parked), per day;
- 600 kW electric motor.
- Passengers transported per day in the peak period.
  - 58 (vehicles)*(400 passengers/vehicle)*10 (hours of operation/day - 10 cycles of the Functional Unit) = 232,000 passengers.
- Passengers transported per day in the valley period.
  - 26 (vehicles)*(400 passengers/vehicle)*10 (hours of operation/day) =104,000 passengers.
- Daily (total) consumption of the fleet.
- Peak operation:
  - 58 (vehicles)*10 (hours)*600 (kW) = 348,000 kWh.

Note: Each vehicle operates with 6 engines of 100 kW each, consuming 600 kW per hour of operation (VOSSLOH, 2016).

- Valley operation:

26 (vehicles)*10 (hours)*600 (kW) = 156,000 kWh.

The fleet's daily consumption is 504,336 kWh.

The total energy consumed by the LRT fleet over 30 years of operation is calculated using Equations AIII-5 and AIII-6.

- Energy consumed by the LRT fleet (kWh) over 30 years of operation:

504,336 * 300 * 30 = 4,539,024,000 kWh **(AIII-5)**

Since 1kWh = 3.6 j (TÁVORA, 1975), then:

- Energy consumed by the LRT fleet (Tj) over 30 years of operation:

4,539,024,000 kWh * 3.6 = 19,880,925,120 = 16,340,486,400 Mj = 16.34 Tj **(AIII-6)**

This is the amount of energy used in the study of the Vehicle Energy Efficiency criterion. The cost of this energy is calculated using Equation AIII-7.

- Cost of energy consumed by the VLT fleet over 30 years of operation:

4,539,024,000 kWh * BRL 0.324 (cost of 1.0 kWh according to AES (2017))

= BRL 1,470,643,776.00 = US$ 435,101,708.88 (conversion rate adopted by the author is 3.38; BACEN (2017) JAN/2017) **(AIII-7)**

This is the amount that could be used in the study of the Economic and Financial Feasibility criterion but, the cost of energy is already considered into the operation and maintenance costs (CSOMV and CSOMI).

Note: The transportation capacity of 330,000 p/day, used in the above assessments, is operational. However, the maximum daily transport capacity defined by the Functional Unit as 340,000 p/day can be met with the estimated fleet, by adjusting with the number of vehicles allocated as “operational reserve”.

MNT

Per day, the system carries a total of 330,000 (load adjusted to the vehicle’s capacity) passengers and consumes 462,000 kWh. It is noted that these numbers may vary depending on variations in peak and valley intervals and the number of vehicles in reserve that can be used in the mainline, when necessarily. These figures were calculated similar as done for the LRT, adopting a daily operation of 20 hours, 10 hours in peak (24 vehicles operating and 3 in operational standbys) and 10 hours in valley (12 vehicles operating and the others parked).

- Daily fleet loading.
  - In peak period:

24 (vehicles)*(1000 passengers/vehicle)*10 (hours of operation/day – 10 cycles of the Functional Unit) = 240,000 passengers.

- In daily Valley period.
  - 9 (vehicles)*(1000 passengers/vehicle - of 7 cars)*10 (operating hours/day)

= 90,000 passengers.

Total: 330,000 passengers per day.

- Daily consumption of the fleet.
- In daily Peak operation:

24 (vehicles)*10 (hours)*1400 (kW) = 336,000 kWh.

Note: Each vehicle operates with 14 engines of 100 kW each, consuming 1400 kW per hour of operation (AEAMESP, 2013).

- In daily Valley operation:

9 (vehicles)*10 (hours)*1400 (kW) = 126,000 kWh. Total: consumption of 462,000 kWh per day.

The total energy consumed by the MNT fleet over 30 years of operation is calculated using Equations AIII-8 and AIII-9.

- Energy consumed (kWh) by the MNT fleet over 30 years of operation:

462,000 * 300 * 30 = 4,158,000,000 kWh **(AIII-8)**

In joules (Equation AIII-9), the value in liters is multiplied by 3.6 (TÁVORA, 1975)

- Energy consumed (Tj) by the MNT fleet over 30 years of operation:

4,158,000,000 kWh * 3.6 = 14,968,800,000 Mj = 14.97 Tj **(AIII-9)**

The cost of energy consumed by the MNT fleet is calculated with Equation AIII-10.

- Cost of energy consumed by the MNT fleet over 30 years of operation:

4,158,000,000 kWh * BRL 0.324 (cost of 1.0 kWh, according to AES (2017)) = BRL

1,347,192,000.00 = US$ 398,577,514.79 (conversion rate adopted by the author: 3.38 : BACEN (2017) JAN/2017) **(AIII-10)**

This is the amount that could be used to study the Economic Performance (or Economic Feasibility) criterion. This procedure is not performed in this study, since already considered into the Operating costs criteria (CSOMV and CSOMI).

Note that there are inaccuracies that occur when carrying out a long term economic feasibility analysis such as the one in this study, which defines a system useful life of 30 years. This is due to variations that may occur in the costs of diesel oil and electricity and also to variations in the dollar conversion rate throughout this period of time. These inaccuracies deserve a future study on how to minimize such effects.

Note: The maximum daily transport capacity defined by the Functional Unit of this case study is 340,000 passengers. This value can be met by adjusting, when necessarily, the number of vehicles allocated in operational reserve (standby).

Subcriteria of cost for operation and maintenance for vehicles (CSOMV) and vehicle's Rolling Infrastructure (CSOMI)

Based on the bibliography consulted, the estimated total operating costs (fixed plus variable) for the operation of each modal, in cost per passenger transported per day, are:

BRT - US$ 1.1; LRT - US$ 0.65 and MNT - US$ 0.59. The memory of the calculation of the amounts for the CSOMV and CSOMI costs for the operation of the modals in the functional unit follows.

As the functional unit has as a requirement the daily operational load of 330,000 passengers, daily operating costs will be: BRT - US$ 363,000.00; LRT - US$ 214,500.00 and MNT - US$ 194,700.00.

These operating costs were divided into vehicles (CSOMV) and infrastructure (CSOMI), assuming the assumption of 90% and 10%, respectively. This division was based on the average of preferences (or, let's say, in this case experience) of the Operator class agents, who responded to the forms or were interviewed in the survey. With these assumptions, follow the daily costs for the CSOMV and CSOMI criteria:

- CSOMV: BRT - US$ 326,700.00; LRT - US$ 193,050.00 and MNT - US$ 175,230.00;
- CSOMVI: BRT - US$ 36,300.00; LRT - US$ 21,450.00 and MNT - US$ 19,470,000.

BRT

The BRT line that operates bi-articulated vehicles in Curitiba has an operating cost per passenger transported of R$ 0.69 (based on January 2009). This cost considers already all fixed and variable costs (LERNER, 2009).

Using this R$ 0.69 information, plus the conversion rate of R$ 2.38 to the dollar of January 2009 (BACEN, 2017), the cost is US$ 0.29 per passenger transported. With this parameter, the daily operational cost of the Functional Unit, as reported by SPTrans, during a presentation at the Urban Mobility Forum held in São Paulo under the sponsorship of the Public Ministry (MP-SP), in October 2013, has the value of R$ 3.8 per passenger transported. The presentation also has informed that this value takes into account the fixed and variable costs of the transport service, without public subsidies. It was emphasized, however, that the operation is carried out with a public subsidy of R$ 0.8per passenger, which results in the final value of R$ 3.0 (LOPES, 2013).

Using this information (R$ 3.0) and the conversion rate of R$ 2.02 to the dollar of May 2013 (BACEN, 2017), the cost is US$ 1.49 per passenger transported.

The EMTU Operator of the intercity bus system running in São Paulo declared, at the same Urban Mobility Forum, the value of R$ 3.31 per passenger transported. With the same exchange rate per passenger transported, the cost is US$ 1.64.

The mean between the three values (US$ 0.29, US$1.49 and US$1.64) is US$ 1.14. The value of US$ 1.1 is used in this study. With this parameter, the daily operating cost of the functional unit is calculated using Equation AIII-11.

- BRT daily operating cost.

Operating cost / day = 330,000 (passengers) * US$ 1.1 = US$ 363,000.00 **(AIII-11)**

LRT

The operational costs of the LRT, which has rail characteristics, vary greatly from country to country depending on the local costs of wages, energy, services and materials for vehicle maintenance and also for services and materials for the construction of the track infrastructure (RAIL SYSTEM NET , 2010; KÜHN, 2002).

The Light Rail of Calgary City, as an example, is a system that has been under operation for over 36 years. The system has a passenger load of around 300,000 passengers per day. The stated operating cost for this system is US$0.27 per passenger carried. This is a low value, justified because the work was built in an integrated way with the buses modes, and then sharing part of the street-road infrastructure and stations. There were also minimizations in tunnel and viaduct constructions (HUBBELL, 2006; RAIL SYSTEM NET, 2010).

In the United States, the average operating cost of the LRT is on the order of US$ 7.00 per passenger carried (HENRY, 2015; STANGER, 2009).

In Brazil, the LRT is in the beginning of operation with the systems of Baixada Santista and Rio de Janeiro. Therefore, there is little information about its operating costs. The attribution of an operational cost for the LRT takes as a reference, with reservations, the data of the São Paulo Metro. The São Paulo (SP) Metro has an operating cost per passenger transported of R$ 3.19 (base January 2009) per day, on Lines 1, 2, 3, and 5. In dollars at the time, with a conversion rate of R$ 2.38, the value is US$ 1.34. This cost encompasses all fixed and variable costs (LERNER, 2009). More recently, at the Urban Mobility Forum, held in São Paulo in 2013 (LOPES, 2013), the Metro declared a cost of R$ 1.95 per transported passenger. In dollars (conversion rate of R$ 2.02 for May 2013 (BACEN, 2017), the value is US$ 0.97).

In this study, the value of US$ 0.65 is used for the LRT, considering that, although the LRT is simpler than the systems of Lines 1, 2, 3, 4 and 5 of the SP Metro, the Functional Unit of this study requires 68 vehicles and they need maintenance and operators in three shifts to provide the 20-hour service (functional unit requirement).

With the above considerations, the daily operating cost of the LRT is calculated with Equation AIII-12.

- Daily LRT operational cost.

Operating cost / day = 330,000 (passengers) * US$ 0.65 = US$ 214,500.00 **(AIII-12)**

MNT

The Monorail system, like the system of Line 4 of the São Paulo Metro, is a UTO (Unattended Train Operation) system, in which the operation is carried out without drivers on board the trains. On board the trains and on the platforms, attendants are maintained to assist users (passengers). The entire operation is carried out from a control center, which supervises and controls the operation through data and video transmission systems and computers for supervision and control of the Line. Based on the Income Statement made by the Line 4 Concessionaire Operator (São Paulo METRÔ, 2015) an operating cost of US$ 0.23 per transported passenger can be reached.

As for the maintenance costs of Monorails, the São Paulo Metrô concluded that they are not higher than those of subways, based on information provided by the supplier of the Monorail Line 15 system and by entities that operate these systems in Japan. Most of the systems used are similar and the main difference between the two modes is in the way the vehicles are pulled. The subway train uses steel wheel and rail contacts and the MNT runs with a rubber tire over a concrete guide beam. While in the first case there are wear on steel wheel set and rails, in the second there are wear on tires. As for the Monorail beams, data collected by the Metro, together with Japanese operators, inform that concrete beams have never been changed in systems that have been in operation for more than 50 years (SETMSP, 2013).

For the MNT, the operational cost of US$ 0.59 per passenger transported is used in this work. This is a value that lies between the operational cost of SP Metro Line 4 and the cost declared by SP Metro in the 2013 Urban Mobility Forum (LOPES, 2013; BACEN, 2017). The adoption of this value took into account some assumptions. There are information that attributes to the MNT operational costs similar to the ones for Metro and the MNT operation is similar the UTO type, like Line 4. However, as the operation in Brazil is recent, there is a need for more time to collect and analyze more data information for the operational costs for the MNT modal.

With the above considerations, the daily operational cost of the MNT is calculated with Equation AIII-13.

- MNT daily operating cost

Operating cost / day = 330,000 (passengers) * US$ 0.59 = US$ 194,700.00 **(AIII-13)**

System Renewal Cost Subcriteria (CSCR)

In addition to the operation and maintenance costs of the rolling infrastructure and vehicles, an item that stands out in terms of renewal in the operation during the 30-year useful system lifetime is defined by the functional unit concerns the BRT vehicle fleet. BRT vehicles have an average useful life time of 10 years (ARTESP, 2004; SMT, 2015), so they require three fleets. The renewal of the BRT fleet is estimated at US$ 66.8mi (two fleets along 30 years). However, this characteristic of BRT is already considered in the Subcriterion Investment in Vehicles (CSIV).

From the above consideration, the scores (performances) of the CSCR Subcriterion for each modal, which would be 66.8 (BRT), 0.00 (VLT) and 0.00 (MNT), for the purpose of building the pairwise comparison matrix, they are equal to the maximum scores of 10.0 (normalized, meaning 0.3333).

Economic and Financial Feasibility

Concepts

In this item, the three systems are compared in terms of their own capacity to generate cash, to pay the operating costs and to remunerate shareholders' investments at an arbitrated discount rate. The sub-criteria under analysis are:

- Payback Time (TRI, or discounted payback);
- Internal Rate of Return (TIR);
- Net Present Value (VPL - *NPV*).

The three sub-criteria are analyzed based on the cash flow setup, which is basically the projection of the difference between revenues and expenses (investments and operating costs), which occur in a given period. The cash flow may consider, in addition to the inflows and outflows cash arising from the company's (passenger transportation company, in this case) productive activity, other revenues like investments and financial costs such as financing for capital operation. This study is limited to the analysis of operating cash flow, which does not consider financial costs.

The TRI, or period of investment payback, is defined as the number of periods (time unit analysis) required for the shareholder to recoup the initial investment made in the project. This is the time from the beginning of the project, when investments are made, until the moment when the cumulative cash flow changes from negative to positive. The cash flow during this period is calculated by adding the future cash flows (income minus expenses) with the initial investment (initial cost to make the project feasible). For analysis purposes, if the calculated period is shorter than the one defined by investors as acceptable, then the project is accepted. For the TRI calculation to take into account the correction of the future value of money, the cash flow has to be discounted at a certain rate. The payback calculated with the discount rate is so called the discounted payback (BP). When comparing projects with this criterion, the best one is the one with the lowest TRI (CASAROTTO, 1985; McFEDRIES, 2009).

Discounted NPV is a value calculated by bringing all future terms of a cash flow into the present, discounted at an appropriate discount (interest) rate. If the NPV is positive for an investor's defined discount rate, the project will have a financial return greater than its cost of capital. This means that the project will be adding value to the company and to their shareholders. In this case, the project is accepted (feasible in terms of financing evaluation). In comparisons between projects, the best one will be the one with the highest NPV. Equation AIII-14 shows the NPV calculation (CF = Cash Flow for period t; i = discount rate).

- Calculation of NPV

$$\textbf{VPL} = \sum_{t=1}^{n} FCt * 1/(1+i)t \qquad \textbf{(AIII-14)}$$

By definition, the TIR is the rate that results in a NPV equal to zero. It is known as Internal, as it is calculated considering only the revenues and expenses that occur internally to the project (none external capital investments). This sub-criterion is analyzed in conjunction with the so called TMA (Minimum Attractive Rate), defined by the investor as the minimum acceptable rate of investment return for the project. For the project to be accepted, the TIR rate must be greater than the TMA one. The TIR calculation is done by equating the NPV to zero and applying successive approximations until obtaining the discount rate that satisfies this equation. The difference between the TIR and the TMA indicates the degree of risk of the project. The greater the difference (TIR - TMA), the lower the risk of the enterprise (CASAROTTO, 1985; McFEDRIES, 2009).

In summary, the investor has to analyze the three sub-criteria together with the TMA to decide whether or not to approve the project: TIR lower than the maximum defined; TIR greater than the TMA; and the difference (TMA - TIR) within the acceptable risk margin; and positive NPV (CASAROTTO, 1985; McFEDRIES, 2009).

Results

The three sub-criteria were quantified (Table AIII-1) in simulations that had as inputs the net revenues from the tariff paid by users, the costs of investments in the vehicles and the operating costs. The revenues from this study are based on the fare collection calculated with the maximum daily load defined in the functional unit, which is 340,000 passengers.

Modal	TRI (Year)	TIR (%)	VPL (NPV) (US$ mi)	Minimum Atractivity Rate (TMA) (%)
BRT	9,8	7,0	14,2	
LRT	7,8	11,0	1.600,0	7,0
MNT	2,6	38,0	11.900,0	

Table AIII-1 - TRI, TIR, VPL (*NPV*) for BRT, LRT and MNT modes.
Source: Prepared by the author.

Memorandum for calculating the sub-criteria of Table AIII-1

Assumptions

- Cash flows and sub-criteria TRI, TIR and VPL (*NPV*) (Figures AIII-8 to 11) calculated: with Excel spreadsheets (McFEDRIES, 2012); with revenues and costs according to Table AIII-2; Tariff of R$ 3.80 and without CSII (Infrastructure Investment Cost);
- Cost simulations made for BRT with operating costs of 1.0 and also with 1.1 US$ per passenger transported.

<table>
<tr><td>Total system life cycle time</td><td colspan="4">30 years</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Anual Revenue</td><td colspan="2">BRT</td><td>LRT</td><td>MNT</td></tr>
<tr><td>340.000 p/d *300 d * R$ 3,8 /p /3,175 (US$*103)</td><td colspan="2">122.078</td><td>122.078</td><td>122.078</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Costs</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>CSII (US$ mi/km; 12,9 km)</td><td colspan="2">-</td><td>-</td><td>-</td></tr>
<tr><td>CSIV (Fleet - US$ mi)</td><td colspan="2">100,2</td><td>432,0</td><td>321,3</td></tr>
<tr><td>CSOMV+ CSOMI (US$ mi/day)</td><td>340,0</td><td>374,0</td><td>221,0</td><td>200,6</td></tr>
</table>

Table AIII-2 - Data for preparing the project’s Cash Flow.
Source: Prepared by the author.

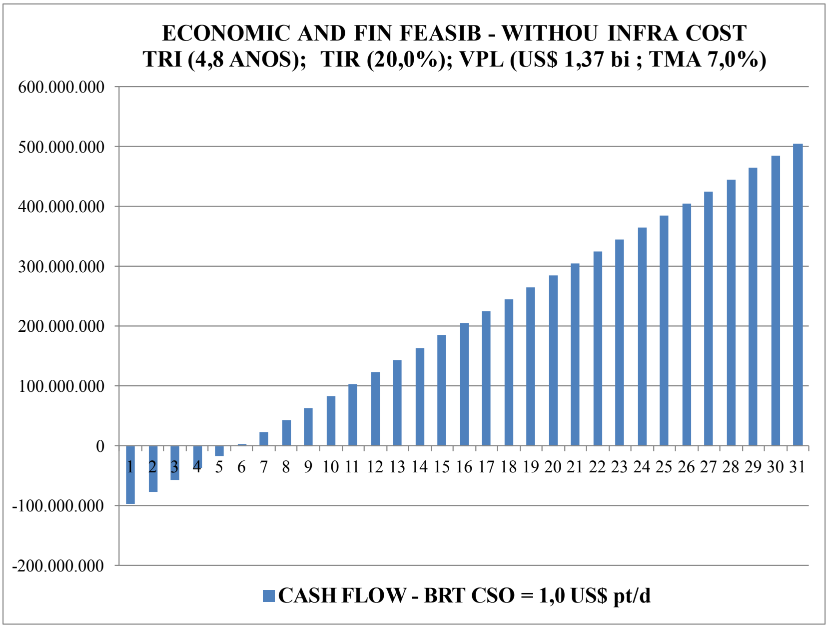

Figure AIII-8 - Financial Valuation - BRT - CSO = 1.0 US$ pt/d.
Source: Prepared by the author.

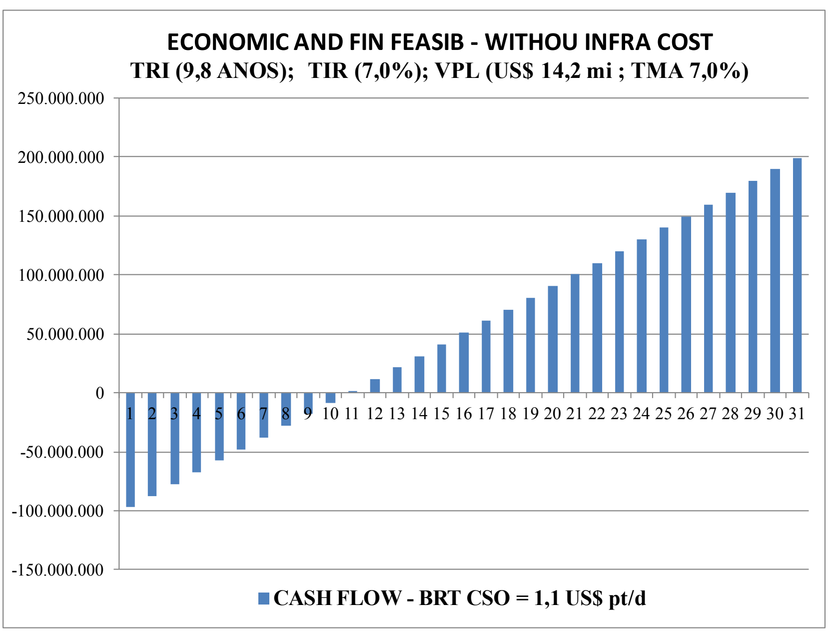

Figure AIII-9 - Financial Valuation - BRT - CSO =1.1 US$ pt/d.
Source: Prepared by the author.

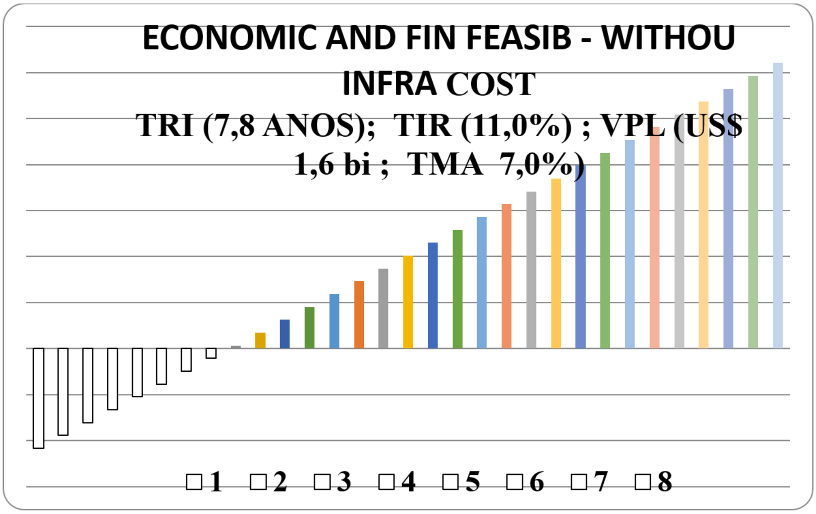

Figure AIII-10 - Cash Flow - VLT.
Source: Prepared by the author.

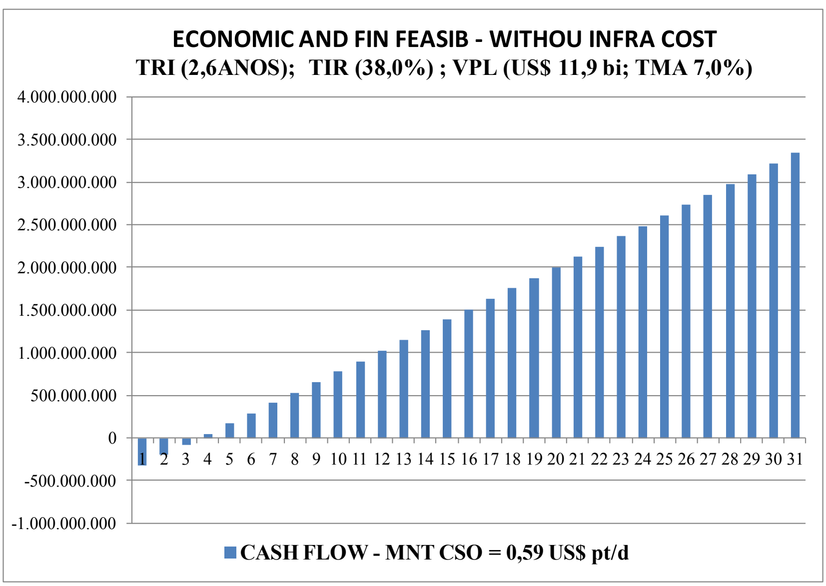

Figure AIII-11 - Cash Flow - MNT.
Source: Prepared by the author.

Comments

The operating cost index has a great influence on project performance. BRT has the highest rate among the three modes. Figures AIII-8 and AIII-9 show the simulations made for the BRT with rates of 1.0 and 1.1 US$ per passenger transported.

Investment in road infrastructure (CSII) was not considered in the cash flow as it is a very high amount, which can be financed exclusively with revenue from tariff collection. This cost must be treated with external financing in addition to the project's internal tariff collection. Table AIII-3 summarizes the results of this brief economic-financial assessment of the three modes.

Modal	TRI (Years)		TIR (%)		VPL (*NPV*) (US$ bi)		TMA (%)	Application of subsidies (according to sources consulted)
BRT (CSO 1,0; CSO 1,1)	4,8	9,8	20,0	7,0	0,014	1,37	7	Yes
LRT	7,8		11,0		1,6			No
MNT	2,6		38,0		11,9			No

Table AIII-3 - Summary of TRI, IRR, VLP criteria for BRT, VLT and MNT.
Source: Prepared by the author.

There are many factors whose changes over time were not considered in this 30-year lifespan analysis. Such are changes in exchange rates, wages, energy costs, and material costs. All these variables influence the operating and maintenance costs of systems over time.

Energy Efficiency

The metric used for the assessment of Energy Efficiency is 1/EI (Energy Intensity). The energy intensity is the amount of energy (Tj) used by the system during the entire operation according to the Functional Unit (30 years).

The energy intensities are calculated in the CSCE sub-criterion (Equations AIII-3, AIII-6, AIII-9) and are:

- BRT - 29.07 Tj; • LRT - 16.34 Tj; • MNT - 14.97 Tj.

Energy efficiencies are:

- BRT - 0.0344 1/Tj; • VLT - 0.0612 1/Tj; • MNT - 0.0668 1/Tj.

Trip Quality

Safety subcriterion regarding accidents between vehicles of the system (QVSVS)

In this sub-criterion, each of the three modalities receives a subjective score (author), between 1.0 and 10.0, according to the scenario in which each one of them operates in the Functional Unit with respect to the fully manual, manual supervised by ATP (Automatic Train Protection) and fully automatic (also with Automatic Train Protection) modalities. The scores assigned are: BRT - 7.0; LRT - 8.0 and MNT - 9.0. Follow the arguments about the scores.

BRT

BRT vehicles are driven in full manual mode. The functional unit's lanes can accommodate a total of up to 146 vehicles traveling on two traffic lanes, one for each direction of movement. At stations there are double lanes that allow overtaking. Considering this scenario, the (author) has assigned, subjectively, on a scale from 1 to 10, the grade 7.

LRT

LRT vehicles are driven in a so-called manual mode with visual care about obstacles up front, on two separate railway lines, one for each direction of traffic. There are systems in which the driver has trackside signalling assistance, which informs the maximum speeds that must be obeyed on certain segments of the road and also at points where there are devices (track switches) that allow the vehicle to cross from one track to another. The devices are located on the main line and at the turning back regions. The line, depending on the Functional Unit requirements, can receive a total of up to 68 vehicles, 34 on each lane. Considering this scenario, the (author), subjectively, on a scale of 1 to 10, has assigned the grade 8.

MNT

Monorail vehicles are driven in fully automatic mode, with no drivers on board. Trains are controlled by safety systems that guarantees a safety level of one unsafe failure every 10*E-9 years (Railway Standard). According to the Functional Unit of this analysis the system can receive a total of up to 27 vehicles, distributed in the two lanes. Considering this scenario, (author), subjectively, on a scale of 1 to 10, has assigned the grade 9.

Safety related subcriterion for accidents between system vehicles and the ones of the street-road system (QVSVV)

The evaluation of this sub-criterion is made for two situations: elevated infrastructure for the three modes; and elevated for the MNT and at street level for BRT and LRT.

In the first scenario, the three modes receive the same score (level 10.0) because they are completely segregated from the street traffic. In the second one, the scores assigned (author) are: 7.0 (BRT); 7.0 (VLT); 10 (MNT).

Average Speed Subcriterion (QVVM)

The Functional Unit admits two requirements for the minimum average operating speed. One is 35 km/h, in the case of elevated infrastructure. The information obtained, through the research carried out during the elaboration of this study, is that the three modes can meet this speed requirement with the use of operational strategies in the movements and stopping's of vehicles at the stations. Other strategies, which can also be adopted, are the use control by voice communications between the vehicle and the central control operators or even software controlling done by onboard and central control computers. With this argument, the same score (10.0) has been assigned to the three modes.

The other requirement possible is 25 km/h in the case of infrastructure installed at street level. This minimum operating speed was identified (author) as typical in meetings held with technicians of the BRT Expresso Tiradentes and Santos LRT systems. In this infrastructure installation option, the scores assigned (author) are 7.0 (BRT), 7.0 (LRT) and 10 (MNT).

Trip punctuality (trip on schedule) subcriterion (QVPV)

In this subcriterion, each of the modals receives a score (author) in a scale from 1 to 10 depending on the level of the monitoring and train control system available.

The BRT is driven manually and the operator follows a timetable of departure and arrival from the origin and the final destination of the itinerary. It is considered that the floors of the vehicles and the board and unboard points (stations) are leveled. Vehicles have 0.8m wide doors.

The LRT is also manually driven and the vehicle's position is monitored across the track lane by a central computer that tracks the journey with the support of a data telecommunication system. A dashboard on board the vehicle informs the driver if he is ahead or behind in his journey. Based on this information, the driver tries to correct the vehicle's position targeting to meet the timetable, dealing with speeds and dwell times at stopping points. Station and vehicle floors are considered leveled. Each vehicle has two doors per car, each with a total opening of 1.6 m.

The Monorail is a fully automatic system that does not require drivers on board the trains. Travel performance is supervised and controlled in real time by computers that are centrally located in an operational control center. Train and control center computers exchange control information via a data communication system. Software algorithms control speeds and stopping times (dwell), keeping the train carousel in line with travel schedules.

Based on these considerations, each modal was subjectively scored (author), on a scale from 1 to 10: BRT - 5.0; LRT - 7.0 and MNT - 9.0.

Universal Accessibility Subcriterion (QVAU)

The Functional Unit of the case study does not define specific requirements for universal accessibility for passengers with special needs. However, in the visits made (author) to the facilities of the Expresso Tiradentes, the Baixada Santista LRT and at the SP Line 15 Monorail, the presence of visual, sound, horizontal, vertical and finger sensitive (Braille) information on the platforms and sound and visual information in the trains were observed, in the three systems. Elevators and ramps were also found in the three systems. In the MNT of Line 15, there are attendants in the vehicles. As for special places for wheelchair users, places were found in the vehicles of the three systems. In buses there is less internal space for the movement of passengers. In the MNT there is an emergency walkway along the elevated infrastructure and the evacuation of passengers, in the event of system failures, is done with the assistance of attendants. The LRT is the best one to evacuate passengers.

Based on the above information, each modal was scored, subjectively (author), on a scale from 1 to 10: BRT (7.0); LRT (9.0); and MNT (7.0).

Passenger Information Subcriteria (QVSIP)

The score assigned to this sub-criterion was made based on field observations. The functionalities and information equipment for passengers were observed in the BRT Expresso Tiradentes, Santos LRT and Monorail Line 15 system of the São Paulo Metro.

The BRT terminal stations are equipped with sound information systems. All BRT and LRT stations are equipped with sound information equipment. LRT trains are equipped with sound information equipment. The Monorail train scored the highest in this subcriteria, since they are equipped to provide information about the imminence of departure (audible and visual signals), audible and visual warnings in each car about the identification of the next station, as well as the side of the opening doors.

Based on this information, each modal was scored, subjectively (author), on a scale from 1 to 10: BRT (6.0); LRT (7.0); and MNT (9.0).

Vehicle' Internal Noise Subcriterion (QVRI)

In order to determine the internal noise levels, measurements were made (author) on the buses of the Expresso Tiradentes, on the LRT vehicle in Santos and on the MNT train on line 15 of the São Paulo Metro. The values considered are the averages of measurements taken at different points of the vehicles, stationary and in motion, with average speeds, respectively, of 25 km/h for the BRT and LRT and 50 km/h for the MNT. The measurements were made taking care to use the same instrument, with the same calibration. As the analysis is done by comparison, it is understood that the precision of the (same used) instrument does not affect the analysis. The measured values were: BRT - 86.5 db (A); LRT - 84.5 db (A); and MNT - 79.0 db (A).

Environmental Impacts

GHG (GEE) emission subcriteria (IAGE)

BRT

In the calculation of this sub-criterion, it is used the average emission factor of 2.67 $kgCO_2eq$ per liter of diesel fuel burned by the internal combustion engine of the BRT vehicle, added to the average factor of 0.5 $kgCO_2eq$ to produce and distribute one liter of diesel oil (EMBRAPA, 2009; CARVALHO, 2011). The emissions produced over the 30-year useful life are obtained by Equation AIII-15.

- Emission of CO_2eq - BRT Vehicle

Emissions = 3.17 ($kgCO_2eq$ / Liter) * 777,420,000 (liters consumed in 30 years)

= 2,464,421,400 $kgCO_2eq$ = 2,464,421 tCO_2eq **AIII-15)**

Another approach can also be used to calculate this volume of emissions. It consists to estimate the distance traveled by the vehicle fleet during the entire useful life of the system (in the order of 512,460,000 km with a travel cycle of 26 km, 146 vehicles in 10 peak hours and 73 in 10 hours in the valley, 300 days/year and 30 years), multiplying this result by the consumption of diesel oil per km (1.3 l/km: estimate used by SPTRans in São Paulo) and multiply again by the factor 3.17. An estimate of 2,111,848 tCO2eq is obtained, a value very close to the calculation above (Author).

The average between the two estimates is used in this study: 2,288,135 tCO_2 eq.

LRT

The LRT vehicles do not emit CO_2eq in the along region of the line where the electrical vehicle travels. However, they consume electricity, in the case of this reserarch, from the Brazilian National Interconnected System (SIN) electrical' grid. The energy of the SIN is generated by different types of plants, ones emitting and others not emitting GHG. The SIN's average CO_2eq emission factor is published by the Brazilians' Ministry of Science and Technology (MCT, 2017). The average factor published for 2016 is used in this study, which is 81.7 $kgCO_2eq$ per MWh generated. The emissions produced over the 30-year useful life are obtained with Equation AIII- 16.

- Emission of CO_2eq LRT vehicle.

Emissions = 81.7 (kgCO_2eq / MWh) * 4,539,024 (MWh consumed in 30 years)

= 370,838,261 kgCO_2eq = 370,838 tCO_2eq **(AIII-16)**

MNT

The same concepts as for LRT are applicable to MNT. The emissions produced over the 30-year useful life are obtained by Equation AIII-17.

- CO_2eq emission - MNT vehicle.

Emissions = 81.7 (kgCO_2eq / MWh) * 4,158,000 (MWh consumed in 30 years) two

= 339,708,600 kgCO_2eq = 339,709 tCO_2eq **(AIII-17)**

Subcriteria of area occupied in the street-road system by the track Infrastructure (IASO)

The scores for this subcriterion were assigned to each mode in measurements made in field visits at Elevado Costa e Silva (Minhocão), at Expresso Tiradentes and at the Monorail of Line 15 of the São Paulo Metro. The variable used as a reference for this criterion is the average (linear) width of the support pillar, which is installed in the central bed of the street-roadway.

BRT

In the elevated infrastructure, the Tiradentes Express occupies 7.94 m (width of the pillar in cross section). For leveled infrastructure, the “occupancy” (linear width) is 8.5 m in the exclusive lane between stations and 19 m in the stations regions.

LRT

Similar occupancy as to the BRT is used.

MNT

The support pillars for the MNT concrete guide beams on Line 15 are 1.70m in diameter; the lateral space between it and the road guide is 0.80 m. So, the (linear width) occupancy of the road is 3.3m.

Subcriterion of visual aesthetics of the Infra-via (IAVE)

The scores for this sub-criterion were assigned on a scale from 1.0 to 10, subjectively (author), depending on the constructive characteristics of the road infrastructure of each mode.

BRT

The elevated BRT infrastructure has a concrete deck with two lanes, one for each direction of traffic. The visual was considered to be impactful and received a score of 5.

LRT

For elevated infrastructure, a score similar to that of BRT is used.

MNT

The MON infrastructure is built with two raised concrete beams, one for each direction of traffic. The look was considered lighter and less impactful in relation to the infrastructures of the BRT and VLT modes, receiving a score of 7.

Subcriteria for division (separating) the street-road by the Infra of the system (IADV)

In this sub-criterion, the three modes receive the same score for elevated infrastructures (level 10), because they do not share the street-road system. When the BRT and LRT systems have the infrastructures installed, at the street-road level, they receive a score (author) of 5.0 due to the street-road division (street-road lanes are separated).

Subcriterion of external noise caused by the vehicle (IARE)

Below are the values measured externally to the vehicles (author).

- BRT - 88.5 db (A); average of measurements taken externally (3 m) to the buses, on the Tiradentes Express system;
- LRT - 84.5 db (A); average of measurements taken externally (3 m) to the vehicles, on Baixada Santista LRT vehicles;
- MNT - 79.0 db (A); average of measurements taken externally (3 m) to the trains of Line 15 of the São Paulo Metro.

Subcriterion of the system' interference in the surrounding area during its installation (IATI)

The assessment of this subcriterion adopts as indicator the time (schedule) to install the rolling infrastructure for the vehicles, as defined in the Functional Unit. Times estimated are: BRT - 36 months; LRT - 42 months; and MNT - 24 months. Follow the arguments to support those time periods.

BRT

Two time references were taken to estimate the rolling' infrastructure installation (elevated and at street level) for the BRT:

The BRT Expresso Tiradentes installation (elevated) took approximately 36 months for its 11.5 km of extension (BASANI, 2017);

For the design and installation of a typical leveled corridor for BRT, the estimated time is 36 months (LERNER, 2009).

LRT

It uses (author) the installation time similar to that of the BRT plus another 6 months due to the installation of the electric traction power system. So, 42 months for both types, elevated or at street level.

MNT

The real time for the implementation of the MNT rolling (vehicles) infrastructure, to serve the Functional Unit, was 24 months (MECA, 2013).

SUMMARY OF PERFORMANCE OF ALTERNATIVES (TABLE AIII-4)

Criteria / Subcriteria	Metric	Mode – Elevated Infra			Mode - Elevated only for MNT		
		BRT	VLT	MNT	BRT	VLT	MNT
System Cost (CS)							
CSII	US$ mi/km	39,00	59,00	49,32	20,75	47,25	49,32
CSIV	US$ mi a Fleet	100,2	432,0	321,3	100,2	432,0	321,3
CSCE	R$ bi in 30 years	2,380	1,470	1,350	2,380	1,470	1,350
CSOMV CSOMI	US$ p/day	1,1	0,65	0,59	1,1	0,65	0,59
CSCR	Author	10,0	10,0	10,0	10,0	10,0	10,0
Economic and Financing. Feasibility (VEF) – Without INFRA (this would require external financing)							
VEFTRI	Years	9,8	7,8	2,6	9,8	7,8	2,6
VEFTIR	%	7,0	11,0	38,0	7,0	11,0	38,0
VEFVPL	US$ mi	14,2	1,600.0	11,900.00	14,2	1,600.0	11,900.00
Energy Efficience (EE)							

Eficiência Energética (EE)	EE = 1/ IE = 1/Tj	0,0344	0,0612	0,0668	0,0344	0,0612	0,0668
Trip Quality (QV)							
QVSVS	Author	7,0	8,0	9,0	7,0	8,0	9,0
QVSVV	Author	10,0	10,0	10,0	7,0	7,0	10,0
QVVM	Author	10,0	10,0	10,0	7,0	7,0	10,0
QVPV	Author	5,0	7,0	9,0	5,0	7,0	9,0
QVAU	Author	7,0	9,0	7,0	7,0	9,0	7,0
QVSIP	Author	6,0	7,0	9,0	6,0	7,0	9,0
QVRI	dB (A)	86,5	84,5	79,0	86,5	84,5	79,0
Environmental Impacts (IA):							
IAGEE	tCO2eq*106	2,29	0,37	0,34	2,29	0,37	0,34
IASO	m	7,94	7,94	3,3	8,5	8,5	3,3
IAVE	Author	5,0	5,0	7,0	5,0	5,0	7,0
IADV	Author	10,0	10,0	10,0	5,0	5,0	10,0
IARE	dB (A)	88,5	84,5	79,0	88,5	84,5	79,0
IATI	Months	36	42	24	36	42	24

Table AIII-4 - Performance of alternatives - Summary.
Source: Prepared by the author.

ANNEX IV - ITDP - BRT STANDARD SCORECARD 2014

OBJECTIVE

This Annex shows (in extract) the indicators (with their scores) present in the BRT Standard Scorecard 2014 document, which the ITDP uses to internationally certify BRT systems. It also shows the entities that update the Scorecard (ITDP).

The BRT Standard
2014 Edition
Cover Photo: The TransMilenio system in Bogotá, Colombia inspired a wave of BRT innovation around the world.

Cover Photo Credit: Carlos Felipe Pardo

ITDP Institute for Transportation & Development Policy
www.itdp.org

Rockefeller Foundation
www.rockefellerfoundation.org

BARR FOUNDATION
www.barrfoundation.org

ClimateWorks FOUNDATION
www.climateworks.org

giz
www.giz.de

icct
www.theicct.org

UNEP
www.unep.org

BRT Standard Scorecard

CATEGORY	MAX SCORE
BRT Basics (PP. 14–23)	
Dedicated Right-of-Way	8
Busway Alignment	8
Off-board Fare Collection	8
Intersection Treatments	7
Platform-level Boarding	7
Service Planning (PP. 24–30)	
Multiple Routes	4
Express, Limited, and Local Services	3
Control Center	3
Located in Top Ten Corridors	2
Demand Profile	3
Hours of Operations	2
Multi-corridor Network	2
Infrastructure (PP. 31–36)	
Passing Lanes at Stations	4
Minimizing Bus Emissions	3
Stations Set Back from Intersections	3
Center Stations	2
Pavement Quality	2
Stations (PP. 37–41)	
Distances Between Stations	2
Safe and Comfortable Stations	3
Number of Doors on Bus	3
Docking Bays and Sub-stops	1
Sliding Doors in BRT Stations	1

CATEGORY	MAX SCORE
Communications (PP. 42–43)	
Branding	3
Passenger Information	2
Access and Integration (PP. 44–49)	
Universal Access	3
Integration with Other Public Transport	3
Pedestrian Access	3
Secure Bicycle Parking	2
Bicycle Lanes	2
Bicycle-sharing Integration	1
Point Deductions (PP. 50–54)	
Commercial Speeds	-10
Peak Passengers per Hour per Direction (pphpd) Below 1,000	-5
Lack of Enforcement of Right-of-Way	-5
Significant Gap Between Bus Floor and Station Platform	-5
Overcrowding	-5
Poorly Maintained Busway, Buses, Stations, and Technology Systems	-10
Low Peak Frequency	-3
Low Off-peak Frequency	-2

Minimum Requirements for a Corridor to be Considered BRT

1. At least 3km length with dedicated lanes
2. Score 4 or more points in dedicated right-of-way element
3. Score 4 or more points in busway alignment element
4. Score 20 or more points across all five BRT Basics elements

BRONZE 55–69 points | SILVER 70–84 points | GOLD 85–100 points

Table AIV-1 - BRT Standard Scorecard 2014 - Extract 1.
Source: ITDP, 2014.

BRT Basics (PP. 14–23)

Dedicated Right-of-Way	8
Busway Alignment	8
Off-board Fare Collection	8
Intersection Treatments	7
Platform-level Boarding	7

Table AIV- 2 - BRT Standard Scorecard 2014 - Extract 2.
Source: ITDP, 2014.

Service Planning (PP. 24–30)

Multiple Routes	4
Express, Limited, and Local Services	3
Control Center	3
Located in Top Ten Corridors	2
Demand Profile	3
Hours of Operations	2
Multi-corridor Network	2

Table AIV-3 - BRT Standard Scorecard 2014 - Extract 3.
Source: ITDP, 2014.

Infrastructure (PP. 31–36)

Passing Lanes at Stations	4
Minimizing Bus Emissions	3
Stations Set Back from Intersections	3
Center Stations	2
Pavement Quality	2

Table AIV-4 - BRT Standard Scorecard 2014 - Extract 4.
Source: ITDP, 2014.

Stations (PP. 37–41)

Distances Between Stations	2
Safe and Comfortable Stations	3
Number of Doors on Bus	3
Docking Bays and Sub-stops	1
Sliding Doors in BRT Stations	1

Table AIV-5 - BRT Standard Scorecard 2014 - Extract 5.
Source: ITDP, 2014.

Communications (PP. 42–43)

Branding	3
Passenger Information	2

Table AIV-6 - BRT Standard Scorecard 2014 - Extract 6.
Source: ITDP, 2014.

Access and Integration (PP. 44–49)

Universal Access	3
Integration with Other Public Transport	3
Pedestrian Access	3
Secure Bicycle Parking	2
Bicycle Lanes	2
Bicycle-sharing Integration	1

Table AIV-7 - BRT Standard Scorecard 2014 - Extract 7.
Source: ITDP, 2014.

Point Deductions (pp. 50–54)

Commercial Speeds	-10
Peak Passengers per Hour per Direction (pphpd) Below 1,000	-5
Lack of Enforcement of Right-of-Way	-5
Significant Gap Between Bus Floor and Station Platform	-5
Overcrowding	-5
Poorly Maintained Busway, Buses, Stations, and Technology Systems	-10
Low Peak Frequency	-3
Low Off-peak Frequency	-2

Table AIV-8 - BRT Standard Scorecard 2014 - Extract 8.
Source: ITDP, 2014.

Minimum Requirements for a Corridor to be Considered BRT

1. At least 3km length with dedicated lanes
2. Score 4 or more points in dedicated right-of-way element
3. Score 4 or more points in busway alignment element
4. Score 20 or more points across all five BRT Basics elements

BRONZE	SILVER	GOLD
55–69 points	70–84 points	85–100 points

Table AIV-9 - BRT Standard Scorecard 2014 - Extract 9.
Source: ITDP, 2014.

ANNEX V - COMPARISON OF PERFORMANCE - GLT/LRT

INTRODUCTION

This Annex shows the performance comparison between the LRT (Light Rail Transit -Figure AV-2) and the GLT (Guided Light Transit - Figure AV-1) technologies, also known as Tram on Tires or Rubber-Tired Tramway (LIGHTRAILNOW, 2016). The LRT technology is known in Brazil as LRT (*VLT*) (Light Rail Vehicle)[1].

Currently there are GLT(s) systems installed in France (Nancy, Caen and Clermont-Ferrand, Paris), China (Tianjin and Shanghai) and Italy (L'Aquila and Mestre). As an observation, it is noted that the GLT system in the city of Caen is being replaced by the LRT one (KING, 2015, SWEISYSTEM, 2009).

Figure AV-1 - GLT Transnlohr - Clemont-Ferrand.
Source: Translohr, 2017.

1. In this work, the two acronyms refer to the same type of system.

Figure AV-2 - LRT Nantes.
Source: Picture available at <https://www.google.com.br/Nantes>.

The LRT system is currently installed in several cities and in several countries. In Brazil, Santos and Rio de Janeiro cities already have these modes in operation (PREFEITURA-RIO-SECPAR, 2016; BÁFERO, 2012).

The interest in performing this GLT/LRT comparison arose from reading an article (AZEVEDO, 2017), which describes the hypothesis of the implementation of approximately 13 km of GLT or VLT line, in the central region of the São Paulo city.

This comparison was made in a case study using the same proposed process to support the decision to choose the BRT, LRT and Monorail modes, whose main steps are:

- Define the applicable criteria, sub-criteria and alternatives;
- Survey decision agents' preferences by criteria and subcriteria, together with decision agents;
- Raise the scores of the alternatives in compliance with the criteria and subcriteria with experts and/or the applicable and available bibliography;
- Calculate the priority vectors of criteria (VPC), subcriteria (VPSC) and alternatives (VPA);
- Determine the final order of preference of alternatives with the Global Index, calculated by processing the priority vectors of criteria, sub-criteria and alternatives.

CRITERIA AND SUB CRITERIA

Criteria

The relevant criteria selected for the study are: System Cost; Economic and Financial Feasibility; Energy Efficiency; Trip Quality and Environmental Impacts. With the exception of Energy Efficiency, these criteria are broken down into 22 sub-criteria, as described below.

Subcriteria

System Cost (CS)

- Investment in vehicle rolling infrastructure, comprising: rolling lane; passenger embarkation and disembarkation points; traction electric energy distribution system (CSII);
- Investment in vehicles necessary to meet the demand of the Line (CSIV);
- Energy cost to operate vehicles over the lifetime of the system (CSCE);
- Vehicle operation and maintenance cost throughout the system's useful life (CSOMV);
- Cost of operation and maintenance of the track infrastructure throughout the life of the system (CSOMI);
- Cost for renewing the system (track infrastructure and vehicles) over the lifetime of the system (CSCR).

Economic and Financial Feasibility (VEF)

- Payback Time (VEFTRI);
- Internal Rate of Return (VEFTIR);
- Net Present Value (VEFVPL).

Energy Efficiency (EE)

Sub-criteria for Energy Efficiency were not defined.

Trip Quality (QV)

- Safety: accident between system vehicles (QVSVS);
- Safety: accident between system vehicles and the street-road system vehicles (QVSVV);
- Travel time (as a function of average vehicle speed) (QVVM);
- Trip punctuality (function of operation management function) (QVPV);
- Universal accessibility for boarding and disembarking the vehicle (QVAU);

- Passenger Information System (QVSIP);
- Level of noise produced internally to the vehicle's environment (passengers' saloon) (QVRI).

Environmental Impacts (IA)

- Greenhouse Gas Emissions – GHG (GEE) (CO_2eq) throughout the life of the system (vehicle emission) (IAGEE);
- Area of the road system occupied by the road infrastructure (IASO);
- Visual aesthetic impact of the road infrastructure (IAVE);
- Division of the street-road system caused by the vehicle' rolling infrastructure (IADV);
- Noise level produced in the environment external to the vehicle (caused by the vehicle) (IARE);
- Interference (time and logistics) in the surroundings of the system during its implementation (IATI).

CRITERIA PRIORITY VECTORS (VPC) AND SUBCRITERIA (VPSC)

As this case study is made for an hypothetical application in the city of São Paulo city (AZEVEDO, 2017), the VPC and VPSC vectors already developed in this research are used to evaluate the BRT, LRT and MNT modes (Table AV-1). These same two vectors were developed with the survey of preferences of decision agents present in the São Paulo city and, therefore, can be used in this study as it is being done for the same city.

Preferences given by the decision agents to the **criteria** (VPC) and **subcriteria** (VPSC) **after a pairwise comparison** (AHP method)				
Criteria	Subcriteria	VPC	VPSC	Check of the VPC' decomposition
CS	CSII	0,0810	0,4327	1,0000
	CSIV		0,2334	
	CSCE		0,0976	
	CSOMV		0,1454	
	CSOMI		0,0592	
	CSCR		0,0317	
VEF	VEFTRI	0,0372	0,2569	1,0000
	VEFTIR		0,6435	
	VEFVPL		0,0996	
EE	EE	0,1445	1,0000	1,0000

QV	QVSVS	0,4954	0,4079	1,0000
	QVSVV		0,2310	
	QVVM		0,0937	
	QVPV		0,1457	
	QVAU		0,0629	
	QVSIP		0,0198	
	QVRI		0,0390	
IA	IAGEE	0,2419	0,4414	1,0000
	IASO		0,0888	
	IAVE		0,0310	
	IADV		0,0639	
	IARE		0,1501	
	IATI		0,2249	

Table AV-1 - VPC and VPSC Vectors.
Source: Prepared by the author.

ALTERNATIVE PRIORITY VECTOR

This vector is obtained by comparing the performance of each alternative (GLT and LRT) in relation to the criteria and subcriteria.

Cost Criterion

Sub-criteria Investment in Rolling Infrastructure and in Vehicles (CSII+CSIV)

The following costs are taken from AZEVEDO (2017), Lightrailnow (2016) and Sweisystem (2009).

System	**Cost**
LRT Le Man Line	US$ 31.2 mi/km
LRT Paris T-3 Line	US$ 42.5 mi/km
LRT Paris Châtilin-Virofly Line	US$ 40.4 mi/km
LRT for Caen	US$ 16.6 million/km
	LRT Average Cost
	LRT US$ 32.7 million/km

System	**Cost**
GLT Paris CAD Line	US$ 52.7 mil/km
GLT Paris, Saint-Denis Sarcelles Line	US$ 39.6 mil/km
LPG Sao Paulo (R$ to US$ Rate: 3.3)	US$ 24.24 mi/km
	LPG Average Cost
	GLT US$ 38.84 mi/km

Subcriterion Investment in Vehicles (CSIV)

Investments in vehicles are already considered in the previous item.

Subcriteria Cost of Energy for Vehicles traction (CSCE)[2]

The cost of energy is considered the same for both types of vehicles.

Subcriterion Cost of Operation and Maintenance for Vehicle (CSOMV)

The cost of operating and maintaining of vehicles is considered 10% higher for the GLT compared to the average value of US$ 0.65 per passenger transported, due to the periodic replacement of tires.

Subcriterion Cost of Operation and Maintenance of the street-road infrastructure (CSOMI)

The cost of operation and maintenance of the track infrastructure is considered 10% higher for the GLT due to the periodic maintenance that must be carried out in the floor where the vehicle runs (LIGHTRAILNOW, 2016; KING, 2015; SWEISYSTEM, 2009).

Subcriteria Cost for System Renewal (CSCR)

The cost for system renewal is considered equal for both systems.

Economic and Financial Feasibility

Concepts

In this sub-item, the two systems are compared in terms of their own capacity to generate cash, pay operating costs and remunerate the shareholders' investors at an arbitrated discount rate. The sub-criteria under analysis are:

- Payback Time (TRI, or discounted payback);
- Internal Rate of Return (TIR);
- Net Present Value (NPV - *VPL*).

Assumptions

- The three sub-criteria are analyzed based on the assembly of cash flows for the two modes;
- The quantification of the three variables was carried out with the assumptions:
  - Operation in 30 years;
  - Net revenue exclusively (no external subsidies) from the fare paid by users (R$ 3.80 per trip) and estimated maximum daily load (author) at 100,000 passengers;

2. The cost data presented in sub-items 4.1.3 to 4.1.6 refer to this particular work.

- Estimated operating costs of US$0.65 per passenger for the LRT and US$0.72 (10% higher) for the GLT.

Results

The three sub-criteria were quantified (summary in Table AV-2), based on the cash flows calculated for the two modes.

Mode	TRI (Years)	TIR (%)	VPL (NPV) (US$ mi)	Minimum Atractivity rate (TMA) (%)
GLT	7,8	13,46	76,0	12%
VLT	7,1	16,0	216,0	

Table AV-2 - TRI, IRR, NPV for GLT and VLT modes.
Source: Prepared by the author.

Cash Flows

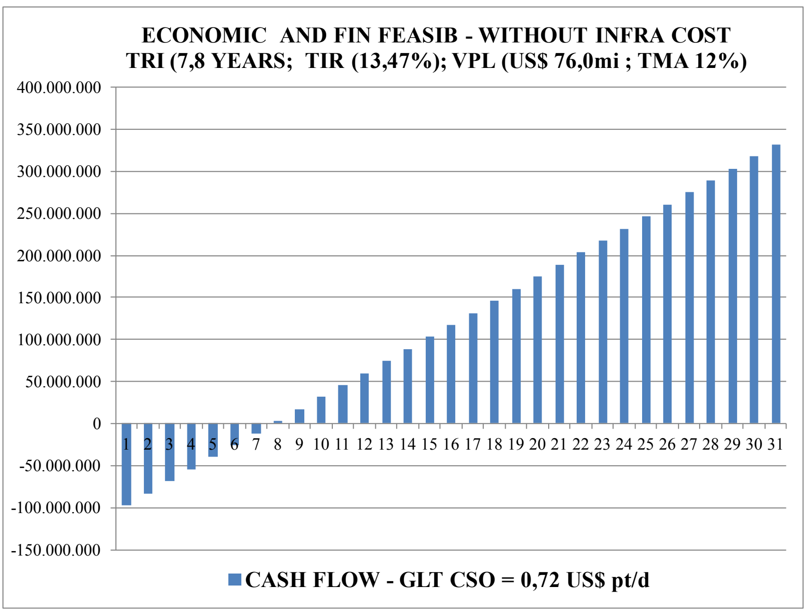

Figure AV-3 - Cash Flow - GLT.
Source: Prepared by the author.

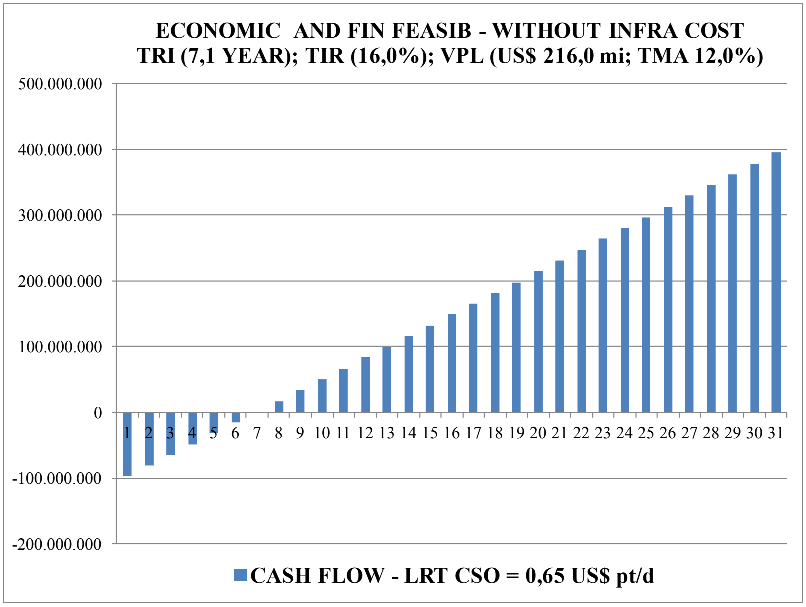

Figure AV-4 - Cash Flow - VLT.
Source: Prepared by the author.

Comments

As shown in Table AV-2, the economic and financial preference is for the LRT: lower TIR, higher VPL *(NPV)* and lower risk (TIR-TMA).

Investments in road infrastructure and vehicles were not considered in the simulations, which have an estimated amount of R$ 1.024 billion (AZEVEDO, 2017). This amount needs to be financed with other sources of funds, in addition to the tariff revenues of the own system.

There are other factors whose variations over time were not considered in this limited 30-year useful life analysis, such as: exchange rate variations; salaries; energy costs; and material costs, among others. All these variables influence the operating and maintenance costs of any systems, along the time.

Energy Efficiency

In this study, the energy efficiency of the two vehicles was considered equal, although the GLT vehicle is slightly less efficient than the LRT due to the contact between the wheels (which uses tires) and the concrete or asphalt floor (vehicle' rolling lane).

Trip Quality

Safety subcriterion regarding accidents between vehicles of the system (QVSVS)

In this sub-criterion, each of the three modals receives a subjective score (author) between 1.0 and 10.0. The scores assigned are GLT - 5.0 and LRT - 9. These scores were assigned after studding reports of derailments that occurred at various facilities with the GLT system (BOMBARDIER, 2017; LIGHTRAILNOW, 2016; KING, 2015; SWEISYSTEM, 2009; TRANSLOHR, 2017).

Safety subcriterion regarding accidents between vehicles of the system and the street-road (QVSVV).

The scores assigned to this subcriterion are GLT - 5.0 and LRT - 9. Same argument as described in the previous item.

Average speed subcriterion (QVVM)

In shared transit, according to the description of the hypothetical application in São Paulo (AZEVEDO, 2017), the two systems will have similar average speeds.

Trip Punctuality (on schedule) Subcriterion (QVPV)

In shared transit, according to the description of the hypothetical application in São Paulo (Ibidem, 2017), the two systems will behave similarly in terms of adherence to the trip schedule.

Universal Accessibility Subcriterion (QVAU)

Built with low-floor vehicles, the two systems will have similar behaviors regarding universal accessibility (BOMBARDIER, 2017; LIGHTRAILNOW, 2016; KING, 2015; SWEISYSTEM, 2009; TRANSLOHR, 2017).

Passenger Information Subcriterion (QVSIP)

Equipped with modern technology for communicating with passengers, the two systems are similarly in terms of QVSIP (BOMBARDIER, 2017; LIGHTRAILNOW, 2016; KING, 2015; SWEISYSTEM, 2009; TRANSLOHR, 2017).

Vehicle Internal Noise Subcriterion (QVRI)

Built with modern technology, the two systems will have similar behaviors regarding the QVRI item (BOMBARDIER, 2017; LIGHTRAILNOW, 2016; KING, 2015; SWEISYSTEM, 2009; TRANSLOHR, 2017).

Environmental Impacts

GEE (GHG) emission subcriteria (IAGE)

As the two systems are driven by electric motors and will be powered from the same source that generates electricity in the hypothetical application in the city of São Paulo, the two systems have similar behavior in relation to the IAGE subcriterion.

Sub-criteria of area occupied in the road system by the Infrastructure via (IASO)

In this regard, the two systems have similarly.

Subcriterion of aesthetic visual of the Infra-via (IAVE)

In this regard, the two systems will have similarly.

Subcriteria for dividing (separating) the street- road Infra (IADV)

In this regard, the two systems have similarly.

Subcriterion of external noise caused by the vehicle (IARE)

In this regard, the GLT will perform better than the LRT, due to the wheels with rubber tires. In subjective scoring, the GLT receives level 9.0 and the LRT 7.0.

Subcriterion of interference in the surroundings of the system during their installation (IATI)

For this subcriterion, the GLT will have a better performance (less installation time) than the LRT, due to having only one guide rail and the LRT two. Besides, the LRT has steel rails to be installed. In subjective scoring, the GLT receives level 9.0 and the LRT 7.0.

SUMMARY OF THE PERFORMANCE OF THE GLT AND LRT ALTERNATIVES

See Table AV-3.

ALTERNATIVE PRIORITY VECTOR (VPA) AND GLOBAL INDEX

The VPA (Table AV-4) is created by normalizing and comparing, pair by pair, the individual performances of each alternative.

Equation AV-1 (SAATY, 1991) shows the additive linear function for calculating the GI of the alternatives. (In the equation, "**m**" is the number of criteria (five criteria in this case), "**p**" is the number of sub-criteria (22 sub-criteria, in this case)) and "**j**" is the number of alternatives (two in this case). The weights or preferences of decision-makers for the criteria and sub-criteria are represented by the letters "**w**" and "**z**" and the performance of each alternative by the letter "**v**".

- AHP Process - Global Index Calculation:

$$\textbf{IG (A}j\textbf{)} = \sum_{i=1}^{m} wi(Ci) * \sum_{k=1}^{p} zk(SCk) * vj(Aj) \qquad \textbf{(AV-1)}$$

CONCLUSION

Within the limits and assumptions of this analysis, as shown by the Global Indices, the LRT (GI = 0.6211) is preferred over the GLT (GI = 0.3789).

Criterion / Subcriterion	Metric	Performances	
		GLT	VLT
System Costs (CS)			
CSII	US$ mi/km	38,84	32,7
CSIV			
CSCE	Same Performances	10,0	10,0
CSOMV	US$ p/day	0,72	0,65
CSOMI			
CSCR	Same Performances	10,0	10,0
Economic and Financing Feasibility (VEF):			
VEFTRI	Years	7,8	7,1
VEFTIR	%	13,46	16,0
VEFVPL (*NPV*)	US$ mi	76,0	216,0
Energy Efficiency (EE)			
Energy Efficiency (EE)	Same Performances	10,0	10,0
Trip Quality (QV)			
QVSVS	Author	5,0	9,0
QVSVV	Author	5,0	9,0
QVVM	Same Performances	10,0	10,0
QVPV	Same Performances	10,0	10,0
QVAU	Same Performances	10,0	10,0
QVSIP	Same Performances	10,0	10,0
QVRI	Same Performances	10,0	10,0
Environmental Impacts (IA):			
IAGEE	Same Performances	10,0	10,0

IASO	Same Performances	10,0	10,0
IAVE	Same Performances	10,0	10,0
IADV	Same Performances	10,0	10,0
IARE	Author	9,0	7,0
IATI	Author	9,0	7,0

Table AV-3 - Performance of the GLT and VLT alternatives.
Source: Prepared by the author.

VPA - After pairwise comparison		GLOBAL INDEX	
GLP	**LRT**	**GLT**	**LRT**
0,1555	0,8445	0,3789	0,6211
0,1555	0,8445		
0,5000	0,5000		
0,1599	0,8401		
0,1599	0,8401		
0,5000	0,5000		
0,1604	0,8396		
0,1555	0,8445		
0,1191	0,8809		
0,5000	0,5000		
0,1346	0,8654		
0,1346	0,8654		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,5000	0,5000		
0,8491	0,1509		
0,8491	0,1509		

Table AV-4 - Alternative Priority Vector and Global Indices GLT and VLT.
Source: Prepared by the author.

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ANNEX VI - EXCEL PLATFORM EXTRACT OF THE CASE STUDY

INTRODUCTION

This Annex shows part of the Excel environment in which the Criteria, Subcriteria, VPC vectors VPC (Criteria Priority Vector), VPSC (Subcriteria Priority Vector) and VPA (Alternative Priority Vector) are mounted, as well as the equations through which the Global Indexes of BRT, VLT and MNT alternatives are calculated.

C	D	E	F	G	H	I	J
Critérios - Preferênciaa dos agentes de decisão (O: Operador; V: Vizinho; U: Usuário; F: Fornecedor; C: Consultor)							
Agntes de Decisão	O	V	U	F	C	Agregação - Média Geométrica das preferências (**valores que são submetidos à comparação par a par**)	
Formulários de avliação	10	22	58	38	10		
CRITÉRIOS	Média Aritmética das preferências						
Custo (CS)	7,1800	3,9091	4,3155	6,4342	4,7500	5,1723	
Viabilidade Econômica e Financeira (VEF)	7,6380	3,7273	4,3716	6,6000	3,4500	4,9031	
Eiciência Energética(EE)	8,1750	5,0000	4,4375	6,1000	4,6667	5,5282	
Qualidade da Viagem (QV)	6,3980	7,0000	7,6164	5,6237	4,9500	6,2446	
Impacto Ambiental (IA)	5,2400	8,0000	5,9241	5,6224	4,6000	5,7749	

Table VI-1 - Criteria - Preferences of stakeholders (agents of decision).
Source: Prepared by the author.

L	M	N	O	P	Q	R	S
Subcritérios - Preferênciaa dos agentes de decisão (O: Operador; V: Vizinho; U: Usuário; F: Fornecedor; C: Consultor)							
Agentes de decisão		O	V	U	F	C	Agregação - Média Geométrica das preferências **(valores que são submetidos à comparação par a par)**
Formulários de avaliação		10	22	58	38	10	
Critério	**Subcritério**	**Subcritérios** - Média Aritmética das preferências					
CS	CSII	7,1700	5,3636	5,3698	6,1039	5,8500	5,9366
	CSIV	6,2250	4,8182	5,4629	6,1513	4,8500	5,4680
	CSCE	7,1800	3,3636	4,3759	5,6776	4,4500	4,8451
	CSOMV	7,0500	3,3636	4,3578	5,7829	4,9250	4,9404
	CSOMI	6,2750	3,1818	3,9388	5,4658	4,1500	4,4696
	CSCR	6,3556	4,0909	4,1238	6,8000	1,8500	4,2266
VEF	VEFTRI	5,2500	3,0909	3,2845	6,1447	4,4000	4,2829
	VEFTIR	6,5556	2,2727	2,8938	6,5833	6,1667	4,4527
	VEFVPL	6,1000	2,1818	2,9298	5,5368	3,4444	3,7521
EE	EE						
QV	QVSVS	7,9100	7,6364	7,9052	8,1816	7,3000	7,7808
	QVSVV	7,6000	7,6364	7,6310	7,9132	7,4000	7,6344
	QVVM	6,8300	5,9091	6,5181	5,9697	4,6500	5,9251
	QVPV	6,9700	6,4545	7,3966	6,6184	6,0750	6,6878
	QVAU	5,4000	5,8182	6,4310	6,0066	4,8250	5,6691
	QVSIP	6,7500	4,9091	6,1147	5,6447	3,5750	5,2762
	QVRI	5,2500	5,0909	6,2703	5,8000	4,9500	5,4507
IA	IAGEE	6,1111	7,9091	6,2789	5,7632	4,9500	6,1303
	IASO	5,2400	6,7273	4,8371	4,3066	3,6750	4,8554
	IAVE	4,6500	6,8182	4,8009	4,5757	3,8500	4,8492
	IADV	5,0000	7,7273	4,7733	5,0842	3,6500	5,0917
	IARE	5,1800	8,2727	5,0862	5,0329	3,3750	5,1724
	IATI	4,2500	7,5455	4,8154	5,1913		5,3210

Table VI-2 - Subcriteria – Stakeholder' preferences (decision agents).
Source: Prepared by the author.

U	V	W	X	Y
Vetor Preferência de **Critérios** (VPC) Vetor Preferência de **Subcritérios** (VPSC)				
Importâncias (preferências) dadas pelos agentes de decisão aos **critérios** (VPC) e **subcritérios** (VPSC) **após a comparação par a par** (método AHP)				
Critério	Subcritério	VPC	VPSC	Verificação da decomposição do VPC
CS	CSII	0,0810	0,4327	1,0000
	CSIV		0,2334	
	CSCE		0,0976	
	CSOMV		0,1454	
	CSOMI		0,0592	
	CSCR		0,0317	
VEF	VEFTRI	0,0372	0,2569	1,0000
	VEFTIR		0,6435	
	VEFVPL		0,0996	
EE	EE	0,1445	1,0000	1,0000
QV	QVSVS	0,4954	0,4079	1,0000
	QVSVV		0,2310	
	QVVM		0,0937	
	QVPV		0,1457	
	QVAU		0,0629	
	QVSIP		0,0198	
	QVRI		0,0390	
IA	IAGEE	0,2419	0,4414	1,0000
	IASO		0,0888	
	IAVE		0,0310	
	IADV		0,0639	
	IARE		0,1501	
	IATI		0,2249	

Table VI-3 – Vectors of Priority of Criteria (VPC) and Subcriteria (VPSC).
Source: Elaborated by the author.

AA	AB	AC	AD	AE	AF	AG	AH
VPA - Desempenho dos modais em cada **critério e subcritério após a comparação par a par** - Infa Elevada				**Índice Global (IG) - Agentes Consolidados**			
BRT	VLT	MNT	Verificação da decomposição do VPA	BRT	VLT	MNT	Verificação da decomposição do IG
0,5508	0,1732	0,2761	1,0000	0,1734	0,2616	0,5650	1,0000
0,8081	0,0610	0,1309	1,0000				
0,0630	0,2232	0,7138	1,0000				
0,0829	0,2385	0,6786	1,0000				
0,0912	0,2453	0,6635	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,1576	0,1860	0,6564	1,0000				
0,1670	0,1780	0,6549	1,0000				
0,0624	0,0854	0,8522	1,0000				
0,0695	0,2287	0,7018	1,0000				
0,0529	0,2114	0,7357	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,0546	0,2004	0,7450	1,0000				
0,0909	0,8182	0,0909	1,0000				
0,0546	0,2004	0,7450	1,0000				
0,2893	0,3236	0,3872	1,0000				
0,1464	0,2801	0,5735	1,0000				
0,1988	0,1988	0,6024	1,0000				
0,1111	0,1111	0,7778	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,2893	0,3236	0,3872	1,0000				
0,1233	0,2189	0,6578	1,0000				

Tabela VI-4 – Vector Priority of Alternatives - Elevated Infrastructure.
Source: Elaborated by the author.

BRT= 0,1734

=W8*X8*AA8+W8*X9*AA9+W8*X10*AA10+W8*X11*AA11+W8*X12*AA12+W8*X13*AA13+W14*X14*AA14+W14*X15*AA15+W14*X16*AA16+W17*X17*AA17+W18*X18*AA18+W18*X19*AA19+W18*X20*AA20+W18*X21*AA21+W18*X22*AA22+W18*X23*AA23+W18*X24*AA24+W25*X25*AA25+W25*X26*AA26+W25*X27*AA27+W25*X28*AA28+W25*X29*AA29+W25*X30*AA30

VLT=0,2616

=W8*X8*AB8+W8*X9*AB9+W8*X10*AB10+W8*X11*AB11+W8*X12*AB12+W8*X13*AB13+W14*X14*AB14+W14*X15*AB15+W14*X16*AB16+W17*X17*AB17+W18*X18*AB18+W18*X19*AB19+W18*X20*AB20+W18*X21*AB21+W18*X22*AB22+W18*X23*AB23+W18*X24*AB24+W25*X25*AB25+W25*X26*AB26+W25*X27*AB27+W25*X28*AB28+W25*X29*AB29+W25*X30*AB30

MNT=0,5650

=W8*X8*AC8+W8*X9*AC9+W8*X10*AC10+W8*X11*AC11+W8*X12*AC12+W8*X13*AC13+W14*X14*AC14+W14*X15*AC15+W14*X16*AC16+W17*X17*AC17+W18*X18*AC18+W18*X19*AC19+W18*X20*AC20+W18*X21*AC21+W18*X22*AC22+W18*X23*AC23+W18*X24*AC24+W25*X25*AC25+W25*X26*AC26+W25*X27*AC27+W25*X28*AC28+W25*X29*AC29+W25*X30*AC30

Figure VI-1 - Equations to calculate the Global Index - Elevated Infra.
Source: Elaborated by the author.

AA	AB	AC	AD	AE	AF	AG	AH
VPA - Desempenho dos modais em cada **critério e subcritério após a comparação par a par** - Infa Elevada MNT				**Índice Global (IG) - Agentes Consolidados**			
BRT	VLT	MNT	Verificação da decomposição do VPA	BRT	VLT	MNT	Verificação da decomposição do IG
0,6933	0,1908	0,1159	1,0000	0,1469	0,2306	0,6225	1,0000
0,8081	0,0610	0,1309	1,0000				
0,0630	0,2232	0,7138	1,0000				
0,0829	0,2385	0,6786	1,0000				
0,0912	0,2453	0,6635	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,1576	0,1860	0,6564	1,0000				
0,1670	0,1780	0,6549	1,0000				
0,0624	0,0854	0,8522	1,0000				
0,0695	0,2287	0,7018	1,0000				
0,0529	0,2114	0,7357	1,0000				
0,0833	0,0833	0,8333	1,0000				
0,3333	0,3333	0,3333	1,0000				
0,0546	0,2004	0,7450	1,0000				
0,0909	0,8182	0,0909	1,0000				
0,0546	0,2004	0,7450	1,0000				
0,2893	0,3236	0,3872	1,0000				
0,1464	0,2801	0,5735	1,0000				
0,1988	0,1988	0,6024	1,0000				
0,1111	0,1111	0,7778	1,0000				
0,1429	0,1429	0,7143	1,0000				
0,2893	0,3236	0,3872	1,0000				
0,1233	0,2189	0,6578	1,0000				

Table VI-5 - Vector Priority of de Alternatives - Elevated Infra for the MNT.
And Global Index (IG) – Elevated Infra.
Source: Elaborated by the author.

BRT= 0,1469

=W8*X8*AA8+W8*X9*AA9+W8*X10*AA10+W8*X11*AA11+W8*X12*AA12+W8*X13*AA13+W14*X14*AA14+W14*X15*AA15+W14*X16*AA16+W17*X17*AA17+W18*X18*AA18+W18*X19*AA19+W18*X20*AA20+W18*X21*AA21+W18*X22*AA22+W18*X23*AA23+W18*X24*AA24+W25*X25*AA25+W25*X26*AA26+W25*X27*AA27+W25*X28*AA28+W25*X29*AA29+W25*X30*AA30

VLT=0,2306

=W8*X8*AB8+W8*X9*AB9+W8*X10*AB10+W8*X11*AB11+W8*X12*AB12+W8*X13*AB13+W14*X14*AB14+W14*X15*AB15+W14*X16*AB16+W17*X17*AB17+W18*X18*AB18+W18*X19*AB19+W18*X20*AB20+W18*X21*AB21+W18*X22*AB22+W18*X23*AB23+W18*X24*AB24+W25*X25*AB25+W25*X26*AB26+W25*X27*AB27+W25*X28*AB28+W25*X29*AB29+W25*X30*AB30

MNT=0,6225

=W8*X8*AC8+W8*X9*AC9+W8*X10*AC10+W8*X11*AC11+W8*X12*AC12+W8*X13*AC13+W14*X14*AC14+W14*X15*AC15+W14*X16*AC16+W17*X17*AC17+W18*X18*AC18+W18*X19*AC19+W18*X20*AC20+W18*X21*AC21+W18*X22*AC22+W18*X23*AC23+W18*X24*AC24+W25*X25*AC25+W25*X26*AC26+W25*X27*AC27+W25*X28*AC28+W25*X29*AC29+W25*X30*AC30

Figure VI-1 – Equations to calculate the Global Index - Elevated Infra for the MNT.
Source: Elaborated by the author.

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