Alternatives to reduce congestion and improve the road system using a Multicriteria Decision Analysis: a case study in the city of Campinas, Brazil

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Abstract

The objective of this work is to propose and evaluate different alternatives to reduce the congestion and improve the road system in a critical portion of a major avenue in the city of Campinas, State of São Paulo, Brazil. The alternatives are outlined and selected using Multicriteria Decision Analysis (MCDA), which encompasses three different phases: structuring, evaluation, and recommendation. The underlying goal of this paper is to show how a multicriteria methodology can be applied as a Decision Support Tool for complex problems, such as urban congestion, where many alternatives are available, leading the actors to understand the impacts of their decision and ultimately improving their overall decision-making process.
Keywords: multicriteria analysis, decision making in transportation, decision making urban transport.

1 Introduction

The development on big cities has always been strongly linked to the transportation systems, with the automobile being a key component to the growing and development of urban centers; however, the automobile has contributed further to the overload and decadence of many central areas (Kneib, [15]). As cities grow spreading the urban areas toward the outskirts, the population demands more motorized vehicles, mainly individual vehicles due to their advantages in terms of mobility and comfort (Amancio, [1]). The expansion of cities also increases the frequency of trips and their average length (Rosa, [19]).

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Currently, most of the metropolitan areas in Brazil often face congestion caused by the road system overload; the situation of vehicle excess on the Brazilian road system causes many issues to the users like increase in traveling time, increase in accidents and people being run over, not to mention the increase in fuel consumption and consequent environmental pollution (Ary, [2]).

The purpose of this work is to propose and evaluate alternatives to improve the road system in a critical portion of a major avenue in the city of Campinas, State of São Paulo. The identification of several alternatives and the choice of one among them require a structured way of thinking and learning process for the problem, so this work applies one of the methodologies widely used for decision-making problems of such a nature: the Multicriteria Decision Analysis (MCDA) (Roy and Vanderpooten, [20]). The MCDA assumes that decision processes are complex and aggregate actors with different perceptions about a problem and with different values about the alternatives and results (Montibeller Neto, [18]). So the MCDA methodology works with these assumptions and proposes a structured learning process that ultimately leads decision-makers to better understand all factors and values, weight them and improve the decision quality.

2 Multicriteria Decision Analysis

The MCDA was initially developed during the 70's to face the increasing demand on organizations to consider different perspectives and criteria, often subjective, of many actors during decision-making processes. The MCDA brought the possibility for decision-makers to include in their models all factors judged to be relevant for the decision (Montibeller Neto, [18]).

Many actors participate in this kind of problem and the basic components of a multicriteria problem are described as follows (Mello, [17]):

Decision-makers – Individuals that make the choices and assume preferences like a unique entity, so called decision-maker or agent.
Facilitator – Interprets and quantifies the decision-makers opinion, helps structure the problem, develops the mathematical model and presents the results for decision. He or she must interact with all decision-makers and in a continuous learning process.
Models – Set of rules and mathematical equations that transforms the preferences and opinions in a quantitative output.
Alternatives – Global actions, meaning actions that can be evaluated on an individual basis. They may represent different courses of actions, different hypothesis, and different characteristics.
Criteria – Tools that enable alternatives comparison based on specific points of view. It is the qualitative and quantitative expression of an alternative based on a point of view (Mello, [17])
Attribute – Used to measure to what degree a fundamental objective is reached. As an example, for the objective time of experience, a possible attribute is years of experience (Keeney, [13]).

The MCDA is commonly built on three main phases: structuring, evaluation and recommendation. Structuring is concerned with the problem formulation and objective identification. It aims at identifying, characterizing and organizing the relevant factors to the decision process as follows: define the decision-makers' objectives, identify the feasible alternatives and establish which criteria will impact the decision, among others that depends on the specific problem. The structuring phase is dynamic and interactive, providing a common language to decision-makers, stimulating learning and also stimulating the debate (Bana e Costa et al, [3] apud Mello et al, [17]; Martins, [16]). Evaluation is usually split further in two: *partial evaluation*, when the alternatives are evaluated based on each criteria, and *global evaluation*, when the alternatives are evaluated based on the several partial evaluations.

The first step to run the evaluation phase is to choose one of the many available methods for multicriteria problems: for the sake of classification, many authors separate the so-called French school, that is based on outranking relations and has as the most known methods those from the family ELECTRE and PROMETHEE; and the American school, that is more popular due to the mathematical simplicity of the methods, such as MAUT and AHP.

3 Case study

3.1 Introduction to the problem

This work describes a study done at the City of Campinas, São Paulo, Brazil; Campinas is located 100 km from the state capital, with a population amounting to 1 million distributed in an area of 796.000 sqm (IBGE, [12]). The inefficiencies found in the urban traffic at Campinas have been raising in the past years, and one of the most critical portions in the local traffic is the John Boyd Dunlop Avenue, more specifically the portion of this avenue that crosses the Anhanguera road at the kilometer 96 as showed at figure 3. Many problems were found in this portion of the avenue like congestions on peak periods (8-9am and 5-7pm), growing number of accidents and running over, lack of alternative tracks for drivers and users.

The John Boyd Dunlop avenue is one of the most important avenues in Campinas because it is the linkage between a major road (Anhanguera) – that links the Capital to the Countryside - and neighborhoods on the outskirts of Campinas. In addition to that, the avenue is also a mandatory way for those coming from downtown and approaching colleges (PUCCII and FAC) and hospitals. Lastly but not least, the John Boyd Dunlop Avenue was the avenue with the biggest number of accidents in 2003 (EMDEC, [9]).

3.2 Methodology

As described in figure 1 below, the steps followed in this case study were: structuring, alternatives evaluation and recommendation. Even though they configure a sequence, there is some recurrence during the steps, returning from evaluation to structuring, and from recommendation to structuring and evaluation.

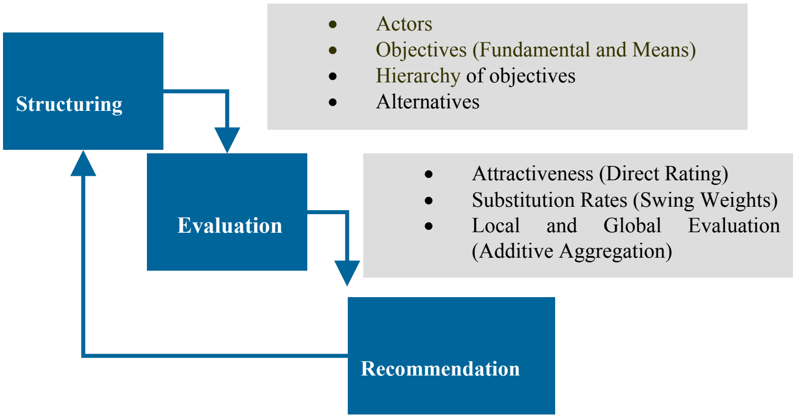

Figure 1: Steps followed through the case study.

3.3 Identification of actors

The first step to identify a solution for the problem of congestion at Avenue John Boyd Dunlop was the identification of the main actors involved in the decision process, after careful considerations and analysis the following groups were identified: **Actors:** public institutions (state government), population (surrounding population and users), private companies (carriers and local companies), road administration company, constructor, environmental organisms; **Decision Makers**: the transportation secretary and the city mayor.

3.4 Fundamental and means objectives

The main challenge of the case study was to identify alternatives that were likely to be common among the actors, considering each point of view and objectives to be achieved (table 1).

3.5 Objectives tree

After identifying and filtering the critical objectives toward eliminating duplicities, aligning to strategic objectives, and grouping the objectives based on their affinities as Costs, Safety, Environmental and Social Impact, Political Return and Comfort, the last step was to define related attributes to each one of fundamental objectives as described in figure 2.

Attention must be given to the attribute assigned to the political return. This is a so-called constructed attribute and the objective is to represent the image and acceptance of each alternative to the population. Each level was assigned as follows: (0) The majority of population disapproves the alternatives, (1) Users support the alternatives, however the surrounding population does not approve, (2) Users and surrounding population approve the alternative, however without publicity throughout the region, (3) Users and surrounding population approve the alternative and in addition to that there will be a plenty of publicity in the region.

Table 1: Fundamental and means objectives.

Actors	Fundamental Objectives	Means Objectives
Public Institutions	Reduce transportation time for users	Approve the best project
	Public approval to the governor	Minimize the project investment
	Reduce health expenses due to accidents	Improve transportation quality to population
	-	Public approval for the project
Users	Reduce transportation time	Increase comfort
	Reduce transportation time and maintenance costs	Increase road safety
	Reduce accidents	-
Local Population	Reduce number of running over	Reduce the average speed
	Increase real state value	Increase road safety
Environmental Organizations	Minimize environment damage	-
	Minimize noise	-
	Minimize pollution	-

3.6 Identification and selection of alternatives

After debates among the actors within the decision context, there was a consensus regarding the feasible alternatives to be considered as likely solutions for the congestion problem. The alternatives are listed below and further identified in figure 3, where the circle is the critical area where congestions takes place.

1. Improve Anhanguera road connection
2. Expand John Boyd Avenue with exclusive bus track
3. Improve Jd Garcia Connection
4. Build connection with Bandeirantes Road

3.7 Assignment of levels to the attributes

During this phase, the levels of the attributes are estimated for each alternative. The environmental impact estimative was based on resolutions from CONAMA [6], the number of accidents was estimated based on published data from the

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Campinas Statistical Transportation Book, by EMDEC for years 2002 and 2003. Table 2 summarizes the levels assigned for each attribute in each alternative, notice the attributes are presented in their original value (R$, ton, minutes, etc).

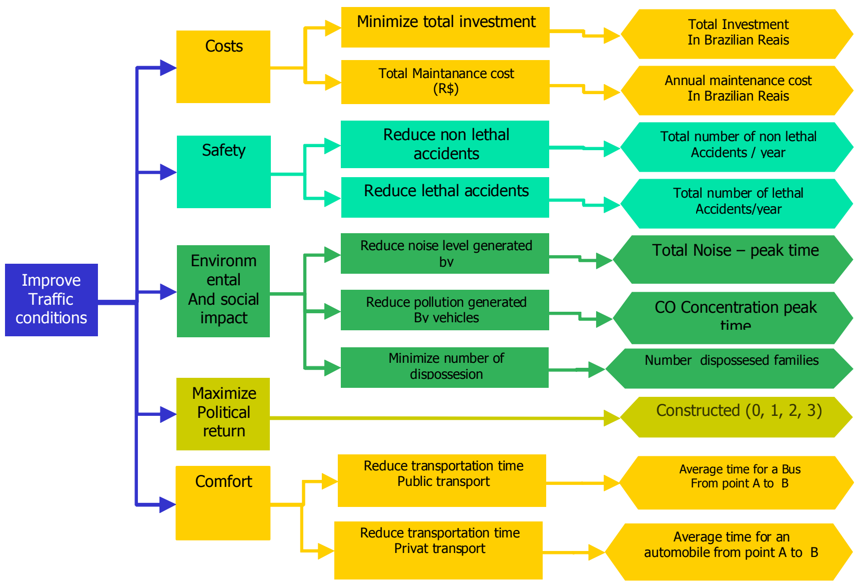

Figure 2: Tree of fundamental objectives and attributes.

Figure 3: Critical portion of John Boyd Avenue with feasible alternatives.

3.8 Value functions

Decision-makers are stimulated to establish the intensity (difference of attractiveness) within a range of values for a specific attribute. The method used for this work was the *direct rating method,* which assigns, for a given attribute, a value from 0 to 100 for each alternative. We can found in figure 4 some examples of the value functions applied to this case. According to Keeney and Raiffa [14], a value function may be considered as a tool that a decision-maker accepts to support the articulation of his/her preferences. After defining the value functions, facilitators are able to build the table with the attractiveness of each attribute for each alternative. The attractiveness at this point may be seen as a common language to evaluate the alternatives.

Table 2: Attribute levels.

		Costs		Safety		Environmental and Social			Politic al retur	Comfort	
		Total Invest. (R$)	Manut Annual R$	Non lethal accidents	Lethal accidents	CO emission (ton)	Noise (dc(	N. Families disposse		Bus time (min)	Auto time (min)
1	Improve Anhanguera road connection	482.800	9.656	20	3	900	85	0	2	8	10
2	Expand John Boyd Av with an exclusive Bus track	818.020	32.720	8	1	1000	85	0	2	10	7
3	Improve Jd Garcia connection	391.000	19.550	15	2	700	70	0	1	8	10
4	Build Bandeirantes Road connection	3.240.370	64.807	10	1	500	70	4	3	3	7

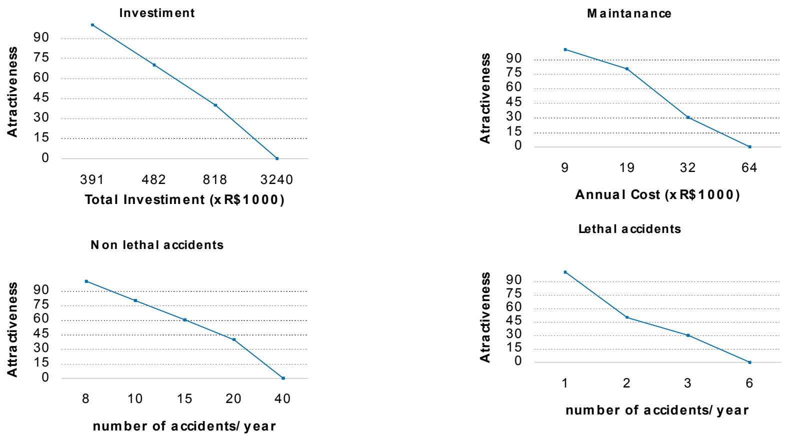

Figure 4: Sample value functions.

3.9 Substitution rates

The substitution rates enable one to assess the relative importance each criteria has in the whole model. Further the substitution rates, multiplied by the values assigned to each attribute, will establish the overall value for each alternative. The method applied toward the definition of such rates was the so-called *swing weights*. The results are presented in figure 5; notice that the *Political Return* was the most important criteria in the given context.

Table 3: Attribute attractiveness.

		Costs		Safety		Environmental and Social				Comfort	
		Total Invest. (R$)	Manut Annual R$	Non lethal accidents	Lethal accidents	CO emission (ton)	Noise (dc(	N. Families dispossе	Political retur	Bus time (min)	Auto time (min)
1	Improve Anhanguera road connection	70	100	40	30	40	0	100	80	70	60
2	Expand John Boyd Av with an exclusive Bus track	40	30	100	100	0	0	100	80	40	100
3	Improve Jd Garcia connection	100	80	60	50	80	100	100	40	70	60
4	Build Bandeirantes Road connection	0	0	80	100	100	100	50	100	100	100

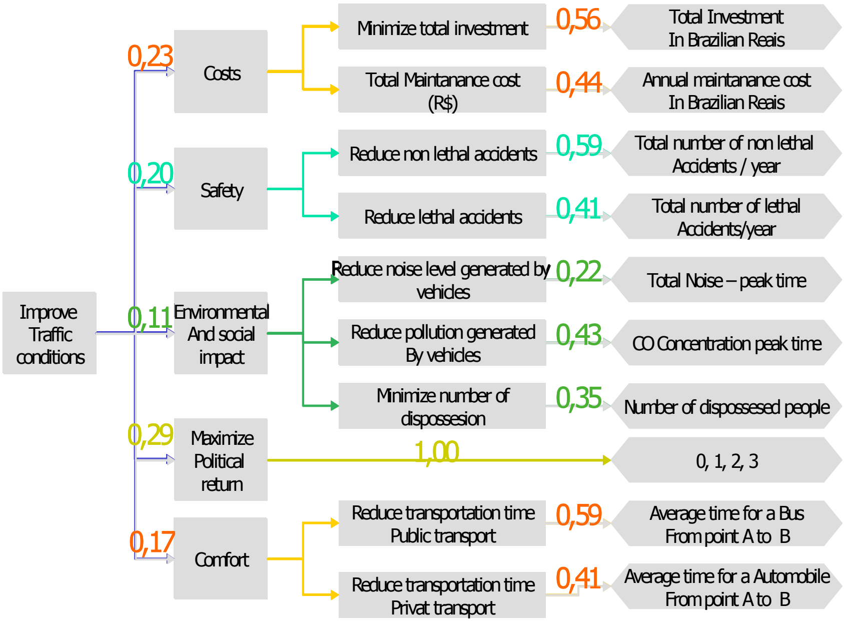

Figure 5: Substitution rates assigned to attributes.

3.10 Global evaluation

The global evaluation is the summation of partial evaluations and is calculated by multiplying the substitution rates by the attractiveness of each attribute from the value function, as follows:

$$V(a) = w_1 * v_1(a) + w_2 * v_2(a) + w_3 * v_3(a) + \ldots + w_n * v_n(a) \,,$$

where:

$V(a)$ – Global value for alternative a;
$v_1(a), v_2(a), \ldots v_n(a)$ – partial values of alternative a for criteria 1, 2, ..., n;
$w_1, w_2, \ldots, w_n$ – substitution rates on criteria 1, 2, ..., n;
n – number of criteria within the model;

Table 4 presents the global evaluation of each alternative to the problem of congestion at Avenue John Boyd Dunlop, based on all criteria established within the problem context and the rank of choices. The chosen alternative must be that with the highest result, in this case, the alternative 4.

Table 4: Global evaluation of the alternatives.

		Costs	Safety	Environment, social impact	Political return	Comfort	Total	Rank
1	Improve Anhanguera road connection	**19,05**	**7,18**	**5,96**	**22,86**	**10,99**	**66,04**	**3º**
2	Expand John Boyd Av with an exclusive Bus track	**8,13**	**20,00**	**3,98**	**22,86**	**12,91**	**67,87**	**2º**
3	Improve Jd Garcia connection	**20,83**	**11,18**	**10,43**	**11,43**	**10,99**	**64,86**	**4º**
4	Build Bandeirantes Road connection	**0**	**17,65**	**9,44**	**28,57**	**17,14**	**72,80**	**1º**

Notice that the alternative 4, *Build Bandeirantes Road Connection*, presents the highest global evaluation, so being the best alternative. It is important to mention that a high importance given to the political return may be one of the reasons to cause this alternative, the most expensive, to be chosen. To further studies, a very interesting proposal is to understand these relations, based on a deep sensibility analysis for each attribute.

4 Conclusions

The purpose of this work was to apply Multicriteria Decision Analysis to a real and complex problem in the transportation area, involving many actors, alternatives and points of view, to show how MCDA methodologies may help decision-makers to understand the factors surrounding and impacting the decision so improving the quality of decisions.

Based on the four alternatives identified, the numbers 1 and 2 act on the avenues and roads located in the critical area, while the alternatives 3 and 4 meant to improve other avenues and roads to detour the traffic and so impact positively the critical region. The chosen alternative 4 was the most expensive, showing that more importance was done to other factors rather than cost; the purpose of including the political return, for instance, as a key criteria, was to create a model closer to the real world, based on the fact that in many decisions of such nature, those political influences are not taken in consideration, and decisions usually go to the opposite side that models suggest.

Lastly, this work also aims at spreading the Multi-Criteria Decision Analysis as a very efficiency tool for improving the decision-making quality mainly for complex problems with many alternatives and many actors involved.

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