STRUCTURING AND EVALUATION OF THE RAILROAD CONNECTION BETWEEN SÃO PAULO METROPOLITAN REGION AND VIRACOPOS INTERNATIONAL AIRPORT

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ABSTRACT

The need to distribute flights in the Southeast region of Brazil brought some issues, such as the feasibility of transportation infrastructure necessary to bridge nucleus population and the airports. Among some discussions, projects like high speed railroad constructions stood out as a modal solution of high capacity and performance, however, there are a few matters to be solved, among others, whether there is the need of a high speed system, known as bullet train, or an inferior speed system would be enough to assure efficiency. The objective of this paper is to structure and evaluate the railroad connection between São Paulo Metropolitan Region and Viracopos International Airport, in Campinas, State of São Paulo. This decision problem was addressed by the Multiple Criteria Decision Aiding methodology, which can be divided into three interacting phases: structuring, evaluation of the alternatives and recommendation. Structuring involved the following steps: characterization of the decision-making context, identification and structuring of fundamental objectives, selection of attributes and assignment of levels to the attributes for each alternative (i.e. bullet train, express train and existing bus system). The evaluation phase was undertaken using the Multi-Attribute Value Function (MAVF) in the additive form. This method encompasses the construction of a value function for each attribute and the assessment of scaling constants. The global evaluation results show that the express train is the most feasible alternative.

Keywords: Rail transport, Multiple Criteria Decision Aiding, São Paulo Metropolitan Region, Viracopos International Airport

INTRODUCTION

The metropolitan regions of São Paulo, Campinas and Rio de Janeiro are some of the most developed in Brazil. They concentrate 45% of the national GDP and 50.8% of the industries, besides being the metropolitan regions with the highest population density. Despite these imposing characteristics, the mobility between these regions is deficient yet.

There is also the overcrowding problem at the Congonhas Airport, in São Paulo, which has suffered from elevated traffic in the last years. One of the options to solve this situation is to transfer part of the flights to the Viracopos International Airport, in Campinas, State of São Paulo.

Some issues emerged from this problem: the transportation infrastructure needed to allow a better integration between the population cores and the airports. In the discussions, the project of a high speed rail link was highlighted as a solution of high capacity and performance. However, there are some issues to be solved, such as whether there is the need of a high-speed system, known as bullet train, or a rail system with lower speed would be enough to assure efficiency.

The aim of this paper is to structure and evaluate the problem of the railroad link between the Metropolitan Region of São Paulo and the Viracopos International Airport.

METHODOLOGY

The decision problem of this paper was handled according to Multiple Criteria Decision Aiding, that considers several criteria and has the purpose to help individual or groups of individuals to explore important decisions (Belton and Stewart, 2002). This methodology is composed of three interacting phases: structuring, evaluation and recommendation.

Structuring involved the following steps: characterization of the decision-making context, identification of fundamental objectives for the studied problem, establishment of the fundamental objectives hierarchy, selection of attributes and assessment of attribute levels for each alternative (i.e. bullet train, express train and existing bus system).

The evaluation is made by means of multi-criteria aggregation methods, which allow both local evaluation of alternatives in each criteria and the global evaluation in the set of criteria. The aggregation method used was the Multi-Attribute Value Function in the additive form, expressed by the following equation:

$$V(A) = w_1.v_1(A) + w_2.v_2(A) + w_3.v_3(A) + \ldots + w_n.v_n(A)$$

where:
$V(A)$ is the global value of alternative A
$v_1(A), v_2(A), \ldots, v_n(A)$ are the individual values of alternative A for attributes 1, 2, …, n

$w_1, w_2, ..., w_n$ are the scaling constants for attributes 1, 2, ..., n
n is the number of attributes

A value function can be considered as a tool that aids the decision-maker to express his preferences (Keeney and Raiffa, 1993, *apud* Ensslin *et al*., 2001). The scaling constants transform local values of preference in global values. In the additive aggregation function, the sum of the scaling constants is equal to one.

In the recommendation phase, sensitivity and robustness analyses can be made to verify if changes in the parameters of the evaluation model interfere in the outcome. This study refers to a real problem, but was performed in the scope of an academic research. For this reason, there are no recommendations, but comments on the results of the evaluation.

CHARACTERIZATION OF THE DECISION-MAKING CONTEXT

The decision-making context is characterized by the following elements: decision level, geographical and time limits, proposed or existing alternatives, type of problem and actors.

Decision Level

The decision level may be strategic, including policies, plans and programs, or refer to a specific project. The railway link discussed in this paper is a project level decision problem.

Geographical and Time Limits

In order to establish the geographical limits in which this study will be performed, it was taken into consideration the metropolitan regions of São Paulo and Campinas, shown in Figure 1. The city of Campinas is 99 km away from the city of São Paulo, the state capital and the biggest city in Brazil. The Metropolitan Region of Campinas encompasses 19 cities with about 2,770,000 total population.

Regarding the time limit of this project, one expects that it will start to operate in a short-term or medium-term basis, because there is the real need to decentralize the flights in the Metropolitan Region of São Paulo. Viracopos International Airport, located 14 km away from the city of Campinas, is the first option because, although today it is mainly an airport of cargo traffic, it has the capacity to receive part of the passenger flights.

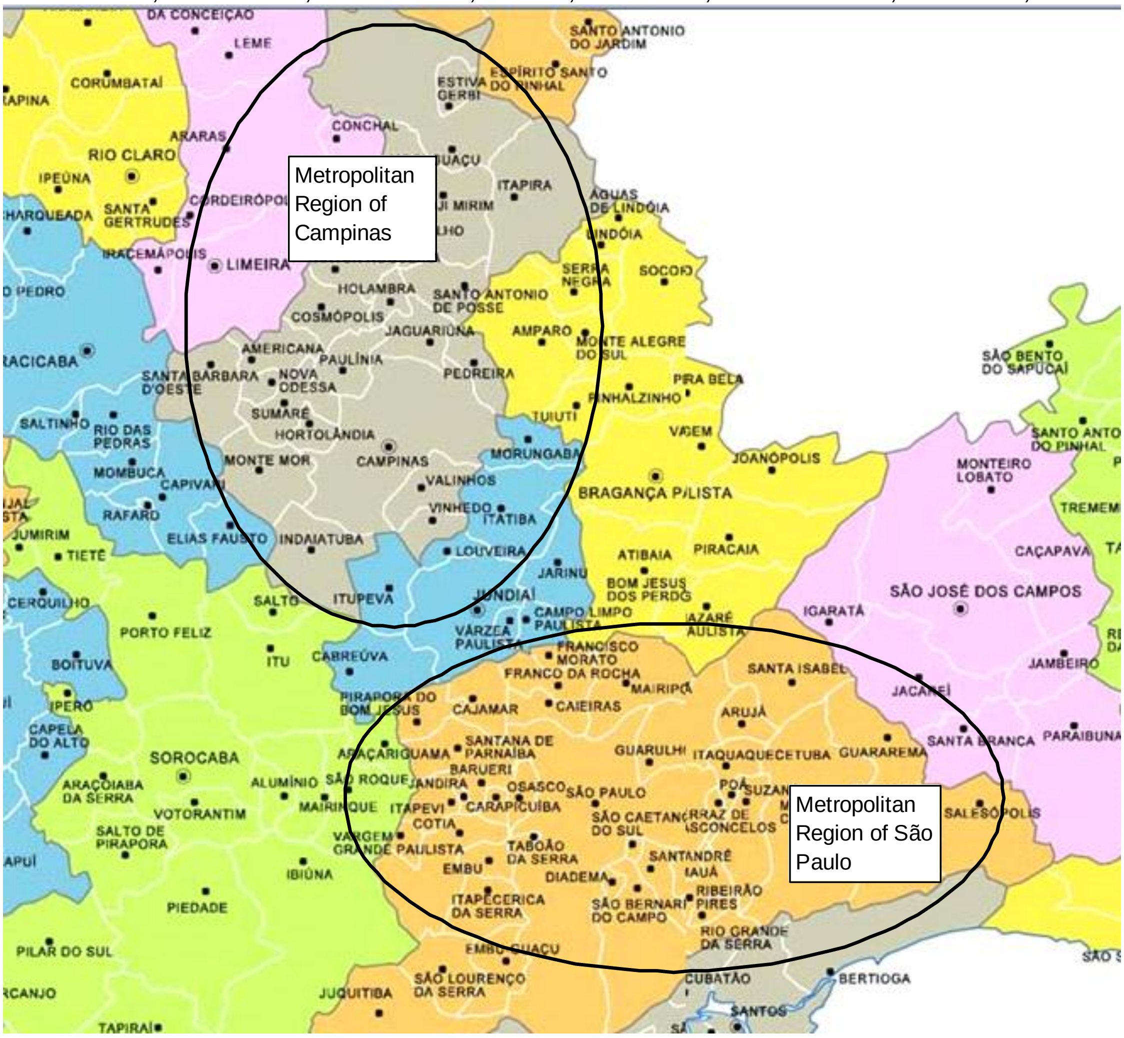

Figure 1 – Metropolitan regions of São Paulo and Campinas (Adapted from IGC, 2002)

Proposed or Existing Alternatives

The two alternatives of railway link already proposed and the existing alternative by bus are described bellow.

Fast Rail Link (express train)

For over 25 years this link has been discussed. Approved by the *Conselho Gestor das Parcerias Público-Privadas – PPS* (Management Council of the Public-Private Partnerships) of the State of São Paulo, the study was dropped. Aboard the Expresso Bandeirantes (as this alternative is named), the passengers would make a comfortable train journey at 160 km/h, with only one stop in the city of Jundiaí, reaching the Viracopos International Airport in 50 minutes.

The idea is so old that the area for the railroad is reserved since the construction of the *Rodovia dos Bandeirantes* (Bandeirantes Highway), in the late 1970s (Thurler, 2008).

High Speed Rail Link (bullet train)

In 1998, the *Empresa Brasileira de Planejamento de Transportes* (Brazilian Company of Transportation Planning) performed a study on the rail link connecting Rio de Janeiro-São Paulo and São Paulo-Campinas (passengers and cargo), with the purpose to reduce costs, time and pollution, besides the improvement of the access to ports in the region (GEIPOT, 2005).

This study proposes a system of High Speed Trains (TAV), based in the conventional technology of “wheel-rail” contact and in the utilization of the lines that are exclusive and protected against noise. There would be eight stations between Rio de Janeiro and São Paulo. The location of the stations joins accessibility criteria (meeting the demands) and characteristics of system performance (maximum speed of 330km/h). The system was conceived to be integrated with the subway, bus terminal, international airports and railway terminals.

Bus (existing situation)

This is the *status quo* alternative. If any of the previous alternatives are not implemented, there is also the option of keeping the connection between the two regions through the road transportation by bus.

Currently, there are three options to this route:

1. From the International Airport of Cumbica to the Road Terminal of Campinas and from it to the Viracopos Airport.

2. From the Airport of Congonhas to the Road Terminal of Campinas and from it to the Viracopos Airport.

3. Direct connection between airports made by some air companies only to their passengers.

Type of Problem

Roy (1985) recognizes four broad types of problems that decision aiding tries to clarify: choice of an alternative, classification of the alternatives in predefined categories, ranking the alternatives, and description of the alternatives and their consequences.

This paper deals with the choice of an adequate railway link between the Metropolitan Region of São Paulo and the Viracopos International Airport, with connections between the airports of Cumbica and Congonhas, in the Metropolitan Region of São Paulo, and Viracopos Airport.

Actors

Even if an individual clearly identified (the decision-maker) is the responsible for the decision, it is the result of interactions between several actors. For Roy and Bouyssou (1993), an actor of a decision-making process is an individual or a group of individuals who directly or indirectly influences the decision.

Initially, the following actors were identified: Ministry of Transport, Ministry of Environment, Ministry of Health, State Secretariat of Health, State Secretariat of Transport, State Secretariat of Planning, São Paulo Metropolitan Train Company (CPTM), Users that travel between São Paulo and Campinas, Brazilian Company of Airport Infrastructure (INFRAERO), Municipal Governments, Population, Air companies and Real Estate Investments Funds.

The power degree and the interest in the decision-making are different for each actor. For this reason a graphic showing the positioning of the considered actors was designed, as suggested by Eden and Ackermann, 1998 (Figure 2).

The actors selected as decision-makers are the Ministry of Transport and the State Secretariats of Transport and Planning, due to their high interest and power. The first author of this paper acted as a facilitator (an actor who supports the decision-makers) and the other authors acted as the decision-makers' representatives.

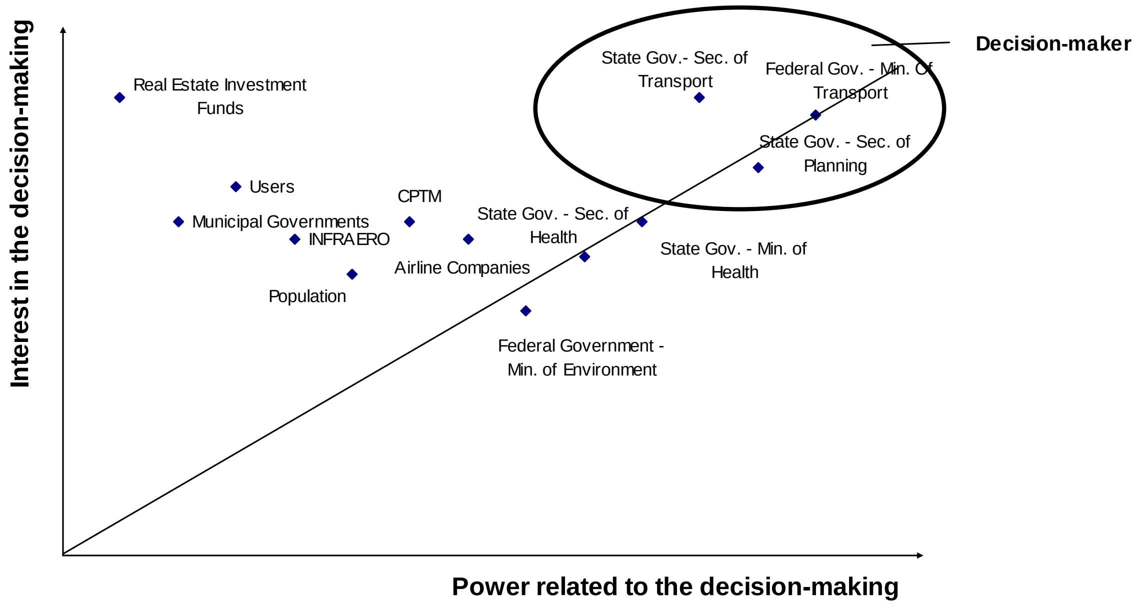

Figure 2 – Interest and power of the actors in the decision-making process

IDENTIFICATION AND STRUCTURING OF THE FUNDAMENTAL OBJECTIVES

Each actor has his own interests in the decision problem dealt with in this paper. Keeney (1992) differentiates fundamental objectives, that represent the values of the actors, and means objectives, that help to achieve those objectives. The fundamental objectives were identified based on the interest of the actors and are listed in Table 1. Following, they were detailed and structured in a hierarchy as shown in Figure 3.

Table 1 – Fundamental objectives of the actors

Considered actors	Fundamental objectives
Ministry of Transport State Secretariat of Transport	To reduce the cost of construction To ensure safety
Ministry of Environment	To reduce the environmental impacts
Ministry of Health State Secretariat of Health	To reduce the direct and indirect costs with population health
State Secretariat of Planning	To improve the integration between airports To attract investments
CPTM	To ensure the passenger demand
Users	To reduce the journey time To create the integration between airports To have comfort in the travel To pay accessible price for the ticket
INFRAERO Airline companies	To improve flight distribution
Municipal Governments	To reduce the interference in infrastructure
Population	To reduce interference in the infrastructure To improve the integration between cities
Real Estate Investment Funds	To attract and create investments

In the fundamental objectives hierarchy, the overall objective is to make the connection viable. The objectives immediately under the overall objective specify its meaning in more detail. These objectives are to reduce the interference in the infrastructure, to reduce environmental impacts, to reduce costs, to attract real state investments, to improve the integration between cities, to ensure demand, to reduce ticket cost, to ensure comfort, and to reduce travel time. Only the objectives to ensure demand and to reduce ticket cost were not further specified.

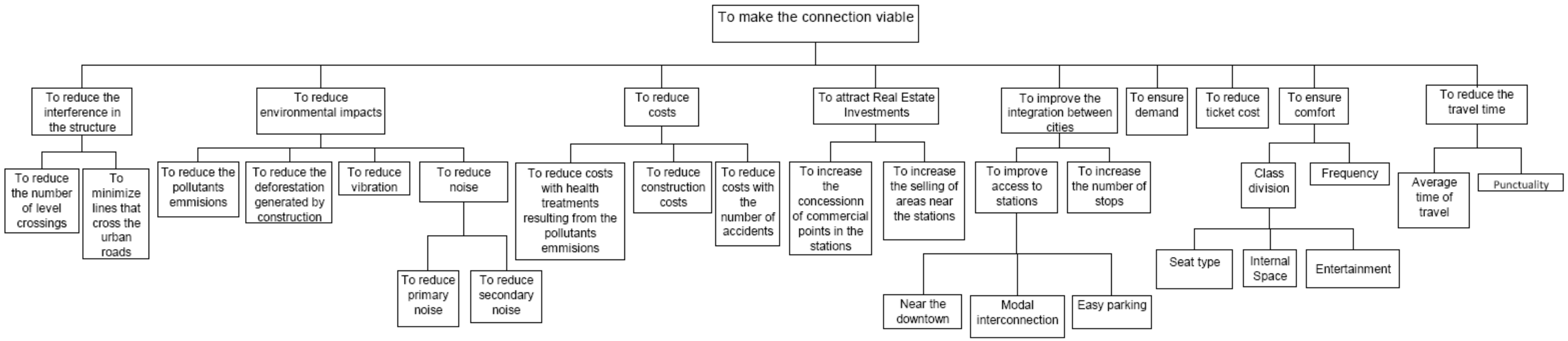

Figure 3 – Hierarchy of fundamental objectives

Source: Developed by the authors

CHOICE OF ATTRIBUTES

To allow the evaluation of alternatives, it is necessary to define attributes that make operational the fundamental objectives. So an attribute, also named descriptor, is associated with each of the lowest-level objectives of the hierarchy. The choice of attributes was based on technical data of the construction studies of the high speed train between Rio de Janeiro and São Paulo, and the express train between the metropolitan regions of São Paulo and Campinas. The data from written media were compiled and suited to this study profile, with the purpose of structuring the problem in a clear and objective way. The chosen attributes are described bellow.

Attributes Description

To reduce interference in the infrastructure

- Level Crossings

One of the prejudicial interferences to the urban environment caused by the railway, cargo or passenger, is the level crossing. It is the point in which the axis of the railway crosses streets or avenues of an urban environment, creating a decrease in the traffic capacity of these places, besides decreasing the safety in case there is no suitable system of passenger and vehicle protection in the case of a train crossing the line.

For the operation of high speed means of transport, the ideal would be no such interference. However, as the railway will pass in some urban routes, it was considered as attribute the number of level crossings. However, it is highlighted that it is necessary to look for technical alternatives that reduce the losses to the operation.

- Railway lines that cross urban areas

The greater the length of the lines that cross consolidated urban areas, the more will be the expropriation costs. Besides, the impacts generated will be higher for the environment and lower will be the performance of the railway model in these parts. The numbers adopted in this paper were based on the study of Bana and Costa *et al*. (2001) for the construction of a new railway access to the port of Lisbon.

To reduce environmental impacts

- CO Emission

With the available data about CO emission (carbon monoxide) of diesel vehicles in the city of São Paulo, according to CETESB (2003) *apud* Freitas (2005), it was calculated the value of the CO emission for the total of buses that traffic between the cities of São Paulo and Campinas. It is known, by the studies performed, that around 12% of the demand of the bullet train would come from the buses. It was considered then, as a better scenario, the decreasing of 12% of buses and it was estimated the correspondent reduction of CO emission, in thousand tons per year. As a worst scenario, it was admitted that there would be no emission reduction.

- Deforestation

The deforestation degree varies according to the characteristics of the environment crossed by the railway. For this attribute, it was adopted the percentage of the layout with need of deforestation. Part of the area between the Metropolitan Region of São Paulo and the Viracopos Airport is already urbanized. However, depending on the kind of layout, some forest areas may be impacted. Layouts with great radius of curves contribute for a greater deforestation, as in the case of the bullet train. For the express train, due to its lower speed, there is more flexibility in the layout, which can reduce the deforestation. The lower level of the attribute is zero, which corresponds to a situation of not having any changes. As upper level, it was admitted a deforestation of 50% relating to the layout.

- Vibration

The chosen attribute considers the speed and frequency of vibration, having adopted the specified interval in the Standard UNE 22-381 (AENOR, 1993) for these parameters. According to this standard, any value out of the interval can bring structural loss to the neighbourhood constructions.

- Noise

Attributes associated to primary noise and secondary noise were chosen. The primary noise is produced by the passing of trains, through the wheel-rail contact, and transmitted by aerial means. The acceptable limit of noise generated by traffic of trains is 85dB (A), to a distance of 5 m in front for the generating source in any condition or location of the rail.

The secondary noise, as the vibrations, is produced by the passing of trains and transmitted by the structures and the ground. According to the Resolution CONAMA nº 001/90, the sound sources emissions must be limited to levels such that they met the Standard NBR 10151 (ABNT, 1987) that considers advisable, for the acoustic comfort, levels of external noise lower than 45 dB (A) (Lage, 2005).

To reduce costs

- Costs of health treatments due to the emissions of pollutants

This attribute was constructed considering the health treatment and internment estimated for the cities of São Paulo and Rio de Janeiro (IPR, 2004).

- Construction costs

The construction costs were estimated based on information presented by the State Government for the construction of the express train (Ribeiro, 2006), and by the Federal Government for the construction of the high speed train (TRANSCORR RSC, 2005).

- Reduction of accidents costs

This attribute was constructed from the data of IPEA (2003), in which the fatal accidents are considered in a monetary way, and DENATRAN (2006), about the estimative of fatal accidents.

To Attract Real Estate Investment Funds

- Selling of commercial points

With the new train stations, new spaces appear for the commerce to the passenger, similar to the commerce in the bus terminals and airports. With the increase of the demand, the interest of the businessmen increase in a proportional way, what makes it interesting to the State government, the selling or assignment of these areas at profitable prices. This kind of transaction helps to replace public resources used in the modal construction. Assuming that the size of a station is similar to the subway or CPTM station, it was considered 10 commercial points per station, to an average selling price of R$ 80,000.00 per point.

- Selling of the areas near the stations

The lands and real estate belonging to the Union or to the State may generate profit for the undertaking, by means of concession or selling. This is in lateral areas to state and federal highways, in which are built undertakings that use the demand created by the modal to attract customers, as is the case of the big restaurants, entertainment centres, hotels and companies of each logistic chain. It was admitted for the calculation of this attribute that the public should make available around 1 million square meters per station, with an average price of R$ 300/m^2.

To improve the integration between cities

- Distance from the station to downtown

The downtown of the cities is the reference of distance established around the world. For this attribute, it is considered a minimum distance of 1km that can be travelled on foot, and a maximum distance of 15 km, that would need other means of transport to access the stations.

- Modal interconnection

All around the globe there is a concern to connect the several modes and assure higher efficiency with each one of them. This way is essential that in the train stations there is the possibility of interconnection with other transport modals. This attribute considers the interconnection with taxicabs, buses and airplanes.

- Parking

There is a portion of users that prefers or needs to go to railway station in automobiles. For these users, is fundamental the existence of private or public parking lots.

- Number of stops

The number of stops directly influences the integration of cities through the railway. Considering the original connection between the city of São Paulo and the Viracopos Airport, a better integration between cities may happen if there were stops in the cities of Jundiaí and also in the center of Campinas that would attract a larger number of passengers. This way, the three options of stops would be: São Paulo and Viracopos; São Paulo, Viracopos and Campinas; and São Paulo, Jundiaí, Viracopos and Campinas.

To ensure the demand

- Passengers demand

Based on the studies undertaken for the high speed train and the express train, the minimum demand considered is 10 thousand passengers per day, and the maximum is 60 thousand passengers per day.

To reduce the cost of the ticket

- Cost of the Ticket

For this attribute, it is considered the cost of the bus ticket and the cost of the automobile trip (toll and fuel).

To ensure comfort

- Type of Seat

The type of seat provides a higher comfort for the passengers. This attribute was created based on the types customarily found on travel buses: conventional, semi-sleeping and sleeping.

- Distance between seats

This attribute was constructed having as basis the distance between the travel bus seats. The bigger the distance, the more comfort for the user.

- Entertainment

For this attribute, two aspects are considered: television devices and the possibility of access to WiFi internet.

- Departure Frequency

The frequency was obtained taking as reference the bus departure interval to Campinas from the Tietê Bus Terminal, in São Paulo. A higher departure frequency, in other words, more trains per hour, ensure a greater comfort to the passengers, because the passenger has more freedom to reach the station.

To reduce the travel time

- Travel time

The minimum travel time was estimated in 30 minutes (high speed train) and the maximum in 80 minutes (bus)

- Delay time

The maximum and minimum delay time were based on Shinkansem (Japanese high speed train), which is a world synonym of performance in high speed rail links. This train is known by the admissible maximum delay of 1 minute. The other times were based on normal delays in bus and automobile trips.

Attribute Levels

For each chosen attribute, it is necessary to define the better viable level and the worst acceptable level. These levels, presented on Table 2, will be used to obtain the value functions.

Table 2 - Attribute Levels

Attribute	Better viable level	Worst acceptable level
Number of level crossings	1	4
Railway lines that cross urban areas (m)	0	3000
Decrease of CO emission (10^3 t/year)	269	Without decrease
Deforestation (%)	0	50
Vibration	Safe (v<5 cm/s and f>30 Hz)	Unsafe
Primary Noise (dB(A))	≤ 85	> 85
Secondary Noise (dB(A))	≤ 30	> 45
Treatment costs (10^6 R$/year)	136	268
Construction costs (10^9 R$)	1	6
Reduction of accident costs (10^9 R$/year)	1,64	1,54
Selling of cCommercial points (10^3 R$/year)	1000	200
Selling of areas (10^6 R$/year)	1000	100
Distance to downtown (km)	1	15
Modal interconnection	Airplane, bus and taxicab	Taxicab
Parking lot	With parking lot	Without parking lot
Number of stops	4	2
Demand (10^3 passengers/year)	60	10
Cost of the ticket (R$)	20	60
Type of Seat	Sleeping seat in leather	Seat fixed in cloth
Distance between seats (cm)	200	90
Entertainment	With TV and WiFi	Without TV and WiFi
Departure Frequency (min)	10	60
Travel time (min)	30	80
Delay time (min)	1	20

CONSTRUCTION OF THE VALUE FUNCTIONS

The value functions were constructed by means of the direct rating and bisection methods (Ensslin *et al*., 2001). In the first method, levels for each attribute, preferably sorted, are defined. To the best viable level is associated the value 100 and, to the worst acceptable level, the value 0. Following, the decision-maker is requested to express the value of the other levels. The method of direct rating was used for the constructed attributes, in which the levels of impact are discreet. The value functions obtained to these attributes are presented on Tables 3 to 15.

The bisection method was used to construct the value functions for the continuous quantitative attributes. In this method, it is necessary to define only the best and the worst levels of each attribute, to which are associated the values 100 and 0, respectively. It is asked, then, that the decision-maker indicates a level of attribute, which the value is half of the extreme values (the best and the worst). It is repeated the procedure for the two sub-intervals, obtaining two other points in the value function. The functions so obtained are showed on Figures 4 to 14.

Table 3 – Value function for railway crossings

Level of attribute	Description	Value
N4	1 level crossing	100
N3	2 levels crossings	50
N2	3 level crossings	25
N1	4 level crossings	0

Table 4 – Value function for the reduction of CO emission

Level of attribute	Description	Value
N4	269.000 t/year	100
N3	180.000 t/year	66
N2	90.000 t/year	33
N1	Without reduction	0

Table 5 – Value function for vibrations

Level of attribute	Description	Value
N2	v < 5 cm/s and f > 30Hz	100
N1	Unsafe	0

Table 6 – Value function for primary noise

Level of attribute	Description	Value
N2	≤ 85 dB(A)	100
N1	>85 dB(A)	0

Table 7 – Value function for secondary noise

Level of attribute	Description	Value
N3	≤ 30 dB(A)	100
N2	>30 and ≤ 45 dB(A)	40
N1	>45 dB(A)	0

Table 8 – Value function for treatment costs

Level of attribute	Description	Value
N4	R$ 136 x 10^6 /year	100
N3	R$ 180 x 10^6 /year	66
N2	R$ 224 x 10^6 /year	33
N1	R$ 268 x 10^6 /year	0

Table 9 – Value function for reduction of accident costs

Level of attribute	Description	Value
N4	R$ 1.64 x 10^9 /year	100
N3	R$ 1.61 x 10^9 /year	66
N2	R$ 1.57 x 10^9 /year	33
N1	R$ 1.54 x 10^9 /year	0

Table 10 – Value function for modal interconnection

Level of attribute	Description	Value
N4	Airplane, bus and taxicab	100
N3	Bus and taxicab	60
N2	Bus	40
N1	Taxicab	0

Table 11 – Value function for parking lot

Level of attribute	Description	Value
N3	With parking lot	100
N2	With paid parking lot	50
N1	Without parking lot	0

Table 12 – Value function for stops

Level of attribute	Description	Value
N3	4 (São Paulo, Jundiaí, Viracopos and Campinas)	100
N2	3 (São Paulo, Viracopos and Campinas)	50
N1	2 (São Paulo and Viracopos)	0

Table 13 – Value function for seat types

Level of attribute	Description	Value
N5	Sleeping seat in leather	100
N4	Sleeping seat in cloth	75
N3	Recliner seat in leather	60
N2	Recliner seat in cloth	30
N1	Fixed seat in cloth	0

Table 14 – Value function for distance between seats

Level of attribute	Description	Value
N5	200 cm	100
N4	150 cm	60
N3	120 cm	40
N2	100 cm	20
N1	90 cm	0

Table 15 – Value function for entertainment

Level of attribute	Description	Value
N4	With TV and WiFi	100
N3	With TV	60
N2	With Wifi	40
N1	Without TV and WiFi	0

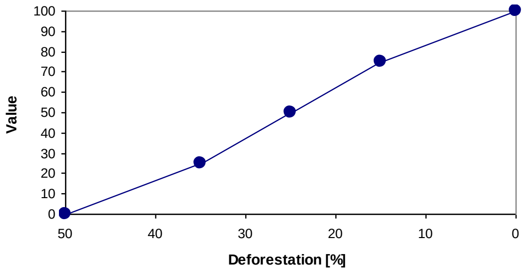

Figure 4 – Value function for deforestation

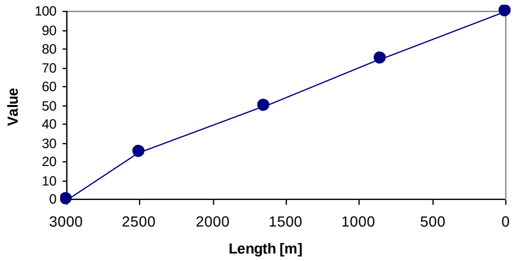

Figure 5 – Value function for rail lines that cross urban areas

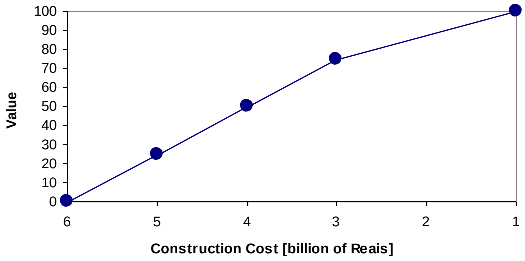

Figure 6 – Value function for construction costs

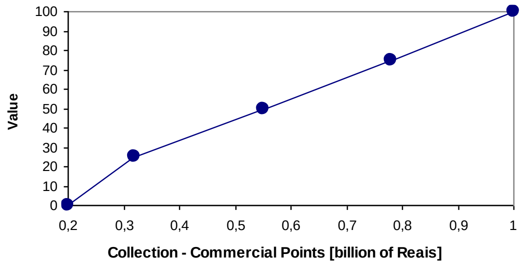

Figure 7 – Value function for selling of commercial points

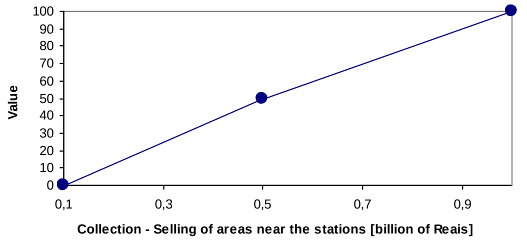

Figure 8 – Value function for selling of areas near the stations

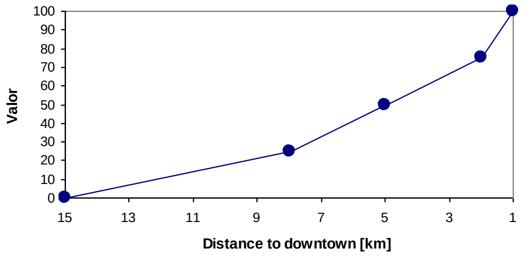

Figure 9 – Value function for distance to downtown

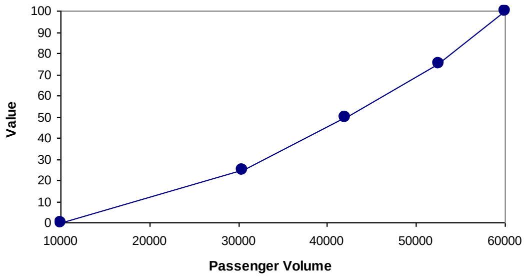

Figure 10 - Value function for demand of passengers

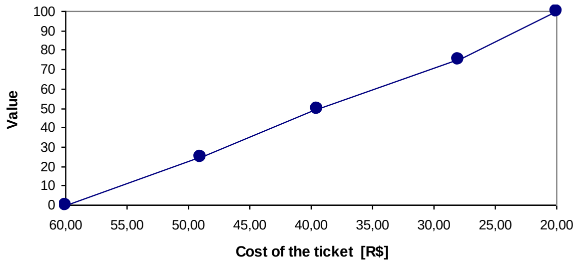

Table 11 – Value function for cost of the ticket

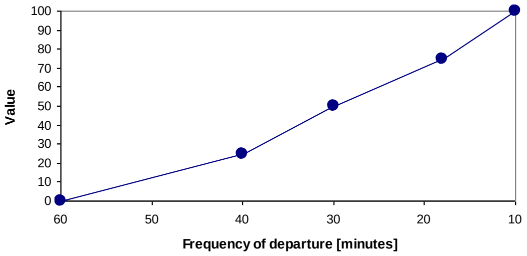

Figure 12 - Value function for frequency of departure

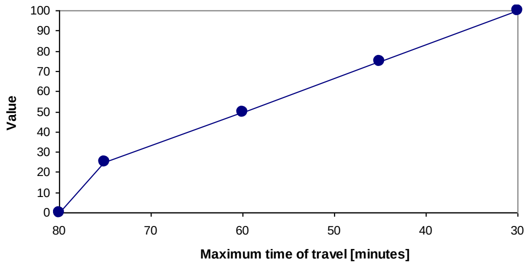

Figure 13 - Value function for travel time

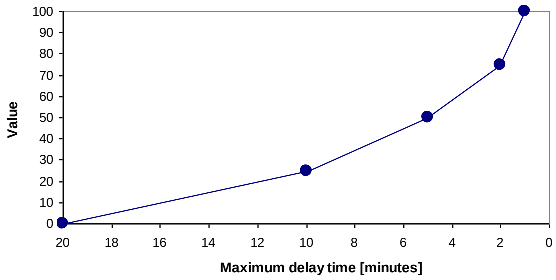

Figure 14 - Value function for delay time

EVALUATION OF ALTERNATIVES

To proceed the evaluation of alternatives, it is necessary to obtain, besides the value function, the scaling constants of the model. They were estimated by the swing weights method (Ensslin *et al*., 2001). Initially, it is considered that all attributes are in the worst level and it is required for the decision-maker to choose an attribute that he would like to pass to the better level. This leap corresponds to 100 points. Following, it is asked to the decision-maker which attribute he would pass from the worst to the better level in second place and how much this leap would worth. The procedure is repeated until the leaps of all attributes are defined. The magnitudes of the jumps are measured relating to the first one. At last, it is made the normalization, obtaining the scaling constants.

The following example shows how were calculated the scaling constants for the attributes of railway crossings and lines that cross urban areas (Table 16).

Jump for level crossings: 100 points
Jump for railway lines that cross urban areas: 80 points

$$\text{Scaling constant for level crossings} = \frac{100}{(100+80)} = 55{,}6\%$$

$$\text{Scaling constant for lines that cross urban areas} = \frac{80}{(100+80)} = 44{,}4\%$$

For the three alternatives considered (bullet train, express train and bus), it was made the local evaluation in each attribute, by means of the value functions. Following, it was used the additive aggregation formula to determine the partial evaluation of each alternative by attribute groups. For example, the fundamental objective “to reduce interference in the infrastructure” is divided in two sub-objectives, that are represented by the attributes railway crossings and lines that cross urban areas. The local evaluation of the bullet train in these attributes is 25 and 100, respectively (Table 16). These values, multiplied by the scaling constant of each attribute, provide the partial evaluation of the alternative in the fundamental objective considered, as follows:

$$V_{infrastructure} \text{ (Bullet train)} = 0{,}56 \times 25 + 0{,}44 \times 100 = 58.$$

Table 16 – Scaling constants and local evaluations

		Local Assessment						
		Scaling Constant	Bullet Train		Express Train		Bus	
			Level	Value	Level	Value	Level	Value
Interference in the infrastructure	Level Crossings	55,6%	3 unit	25	4 unit	0	0 unit	100
	Lines that cross urban region	44,4%	0 m	100	2000 m	41	0 m	100
To reduce environmental impacts	Pollutants Emmissions	16,7%	N4	100	N4	100	N1	0
	Deforestation generated by the construction	33,3%	40%	14	10%	90	0%	100
	Vibration	23,3%	N2	100	N2	100	N2	100
	Noises	26,7%		73,33		73,33		44,44
	Primary Noise	*55,6%*	*N2*	*100*	*N2*	*100*	*N1*	*0*
	Secondary Noise	*44,4%*	*N2*	*40*	*N2*	*40*	*N1*	*100*
To reduce costs	Expenses with health treatment resulting from the pollutant emissions	22,7%	N4	100	N4	100	N1	0
	Construction costs	45,5%	5 bi	25	2 bi	87,5	1 bi	100
	Costs with the number of accidents	31,8%	N4	100	N4	100	N1	0
Attract real estate investments	Concession of commercial points in the stations	66,7%	1 bi	100	1 bi	100	0,2 bi	0
	Selling areas near the stations	33,3%	1 bi	100	1 bi	100	0,1 bi	0
Improve the integration of the cities	Number of stops	44,4%	N3	100	N3	100	N2	50
	Access to stations	55,6%		100		100		64,00
	Proximity of downtown	*36,0%*	*1 km*	*100*	*1 km*	*100*	*1 km*	*100*
	Model interconnection	*40,0%*	*N4*	*100*	*N4*	*100*	*N2*	*40*
	Parking lot	*24,0%*	*N3*	*100*	*N3*	*100*	*N2*	*50*
Ensure Comfort	Frequency	62,5%	10 min	100	10 min	100	10 min	100
	Class Division	37,5%		100		100		52,86
	Seat Type	*47,6%*	*N5*	*100*	*N5*	*100*	*N4*	*75*
	Internal Space	*19,0%*	*N5*	*100*	*N5*	*100*	*N2*	*20*
	Entertainment	*33,3%*	*N4*	*100*	*N4*	*100*	*N2*	*40*
To reduce travel time	Average travel time	54,1%	30 min	100	50 min	81	80 min	0
	Maximum delay time	45,9%	1 min	100	6 min	41	20 min	0

The global value of each alternative is equal to the sum of the partial evaluations in the fundamental objectives of the first level of hierarchy in the Figure 3, namely interference in the infrastructure, environmental impacts, costs, real estate investments, city integration, demand, ticket cost, comfort and travel time. Table 17 presents the evaluations of the three alternatives.

Table 17 - Partial and global evaluations of the alternatives

	Partial Assessment						
	Scaling Constant	Bullet Train		Express Train		Bus	
		Level	Value	Level	Value	Level	Value
Interference in the infrastructure	10,0%		58,33		18,22		100,00
To reduce environmental impacts	10,0%		64,22		89,56		68,52
Minimize costs	12,1%		65,91		94,32		45,45
Attract real estate investments	8,6%		100,00		100,00		0,00
Improve the integrations of the cities	10,0%		100		100		57,78
Ensure the demand	14,3%	60.000	100	60.000	100	20.000	12
Minimize the ticket cost	12,9%	R$ 50	24	R$ 25	86	R$ 20	100
Ensure comfort	9,3%		100		100		82,32
Minimize the travel time	12,9%		100		62,6		0,00
Total Alternatives - Global Assessment		**Bullet Train**	**78,34**	**Express Train**	**83,48**	**Bus**	**50,36**

GLOBAL EVALUATION AND SENSITIVITY ANALYSIS

The global evaluation results show that the Express Train would be the most adequate alternative for the connection between the São Paulo Metropolitan Region and the Viracopos International Airport (Table 18).

Table 18 – Ranking of the alternatives

Classification		
1º	**Express Train**	**83,48**
2º	Bullet Train	78,34
3º	Bus	50,36

The method of Multi-Attribute Value Function allows that the decision-maker expresses his preferences by means of value functions and a set of scaling constants. The fundamental objective "to reduce ticket cost", for example, despite presenting an important scaling constant (12.9%), was not necessarily responsible for the best evaluation of the alternative Express Train. On the other hand, the objective "to ensure demand", also presenting an important scaling constant (14.3%), contributed for the low global evaluation of the option Bus because it performs poorly with respect to this objective.

It can be noted that the Express Train and the Bullet Train have close global evaluations, and that the objectives "to reduce ticket cost", "to reduce environmental impacts" and "to reduce costs" were the ones in which the Express Train obtained better partial evaluation. It is important to highlight that the objective "to ensure comfort" presented values considered good for the three options, and it is possible to conclude that, despite being essential, it did not have great influence in the final decision.

In order to investigate the effect of changes in parameters of the evaluation model on the global evaluation of the alternatives, a sensitivity analysis was carried out. In the Multi-Attribute Value Function method, the parameters are the value functions, the attribute levels for each alternative and the scaling constants.

In this study, the sensitivity analysis consisted in varying the scaling constants on the following fundamental objectives: to reduce costs (w = 12.1%), to ensure demand (w = 14.3%), to reduce ticket cost (w = 12.9%) and to reduce travel time (w = 12.9%). Variations of ± 10% and ± 20% were considered for each scaling constant. The global evaluations of the alternatives resulting from these changes are presented in Tables 19 to 22.

Table 19 – Effect of varying the scaling constant on costs

	- 10%		+ 10%		- 20%		+ 20%	
Alternative	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking
Bullet Train	78,51	2º	78,17	2º	78,69	2º	77,99	2º
Express Train	83,32	1º	83,63	1º	83,18	1º	83,77	1º
Bus	50,43	3º	50,30	3º	50,50	3º	50,22	3º

Table 20 – Effect of varying the scaling constant on demand

	- 10%		+ 10%		- 20%		+ 20%	
Alternative	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking
Bullet Train	77,99	2º	78,69	2º	77.63	2º	79,80	2º
Express Train	83,21	1º	83,74	1º	82,94	1º	84,05	1º
Bus	51,01	3º	49,71	3º	51,65	3º	49,10	3º

Table 21 – Effect of varying the scaling constant on ticket cost

	- 10%		+ 10%		- 20%		+ 20%	
Alternative	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking
Bullet Train	79,16	2º	77,53	2º	79,96	2º	76,73	2º
Express Train	83,45	1º	83,50	1º	83,42	1º	83,54	1º
Bus	49,63	3º	51,09	3º	48,92	3º	51,82	3º

Table 22 – Effect of varying the scaling constant on travel time

	- 10%		+ 10%		- 20%		+ 20%	
Alternative	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking	Global Evaluation	Ranking
Bullet Train	78,03	2º	78,65	2º	77,72	2º	78,97	2º
Express Train	83,80	1º	83,16	1º	84,11	1º	82,85	1º
Bus	51,11	3º	49,62	3º	51,87	3º	48,87	3º

The results of the sensitivity analysis show that the ranking of the alternatives is not affected by changes on the scaling constants, thus confirming the Express Train as the most adequate alternative.

CONCLUSION

This paper approached the structuring and evaluation of the problem of the railway link between the São Paulo Metropolitan Region and the Viracopos International Airport, in the State of São Paulo, Brazil.

The methodology was the Multiple Criteria Decision Aiding, which divides in the phases of structuring the problem, evaluation of alternatives and recommendation. As this study was developed as an academic research, the two first phases were emphasized.

The structuring showed the complexity of the studied problem. The decision-making context is characterized by several actors, with different degrees of interest and power in the decision-making process. The fundamental objectives of the actors were identified, that once detailed and organized in a hierarchy, revealed the wide range of important aspects involved in the problem.

All the fundamental objectives were included in the evaluation of the alternatives, by means of quantitative or qualitative attributes. Two alternatives of railway links (express train and bullet train) were considered, besides the option of not having any changes in the current situation, in which the connection is made by bus. For the evaluation of the three alternatives, it was used the Multi-Attribute Value Function method, in which the preferences of the decision-maker relating to the levels of attributes are aggregated, providing an overall evaluation for each alternative. The results indicate that the Express Train is the most adequate alternative, however with a little difference relating to the Bullet Train.

It is hoped that this paper contributes to highlight the importance of the Multiple Criteria Decision Aiding methodology to the study of complex problems, with the purpose of improving the quality of decision-making.

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