USE OF THE ANALYTIC HIERARCHY PROCESS TO DETERMINE THE TRANSIT FARE SYSTEM

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ABSTRACT

The transportation fare system influences the mobility of a region and the life quality of its inhabitants. This study aims to determine a region's optimal fare system by using the analytic hierarchy process, based on a survey among transportation experts, divided into three categories: operators, professors/consultants and government officials. The results are presented divided by category and overall, and the performance of the most important relative criteria to establish a fare system is determined. The most important criterion according to all the selected experts was the fare price, with 21.5%. The fare system determined as the best was distance/zone (31.1%) and the worst was a flat fare system (7.2%). In addition, we show the influence of the fare price criterion in each fare system through sensitivity charts and highlight its importance for all three groups of experts to determine the fare system.

Keywords: Pricing Strategies, Transportation Planning, Fare system.

INTRODUCTION

According to the United Nations Populations Fund, in 2008 more than half the world's people – 3.3 billion – were living in urban areas. Nearly all projections are that the proportion of urban dwellers will continue to grow substantially in coming years. This places a great responsibility on governments to provide public services, such as water, sewerage, health, education and transportation. To ease problems of urban gridlock and air and noise pollution caused by the use of private cars, it is essential to have low-cost and good-quality mass transit systems.

The provision of urban mobility to large numbers of users traveling different distances and routes at varying hours and frequencies is extremely complex and comes at a high cost to society (Morales, 2007). Therefore, the configuration of a transport system and its scope are fundamental for city dwellers to have an adequate level of mobility.

The transportation system is one of the main factors determining the pattern of urban development, particularly the degree of centralization and the location of areas providing services. A properly designed and fully integrated mass transit system can efficiently cover wide areas, permitting more people to use public transport. Whether the system is totally operated by the government, by the private sector through a concession system, or a mix of the two, an efficient method of financing must be found. This entails public policy decisions on the proper combination of financing from taxes and fares, so that the costs are borne as equitably as possible by all people benefiting directly and indirectly from the system. The fare system influences peoples' commuting choices: public transport (bus, subway, tram, etc.), private car, on foot or bicycle. When there is an integrated public transport system (between modes and lines) that offers good service (in terms of waiting and travel time and information about the system) (Paulley et al., 2006), at affordable fares according to the average income of users and fare integration to facilitate payment, citizens will acquire the habit of using the system. A good public system thus makes cities more livable and economically productive by reducing pollution, congestion and travel times.

The fare system influences various aspects of a region's overall dynamic. Mobility, economic and social development and demographic density are the main factors affected by the fare system and that must be taken into account in formulating one.

There is evidence that simplifying fare structures can do more than reduce the fares paid by most users and increase their number (Gilbert et al.,1991). Well-designed changes in the fare structure can also contribute to greater efficiency, accessibility and safety and reduced pollution (May, A.D., 2006).

Because of the relevance of the subject and its direct connection with life quality, this study aims to contribute to the question of determining the best fare structure in an area.

CONCEPTUAL REVIEW

Fare Policy

According to a study by the National Association of Urban Transport Companies of Brazil entitled "Novas tendências em política tarifária" (Associação Nacional das Empresas de Transportes Urbanos - NTU, 2005), the fare structure is an important part of urban planning policies because it has direct effects on the socioeconomic condition of users, land use patterns and the financial sustainability of transportation systems.

In formulating fare policies, three aspects must be considered (Figure 1):

a) Objectives: the results expected from applying the policy;
b) Fare structure: ways of charging for the services, involving the price level, fare collection strategies and payment options;
c) Payment technologies: tools (equipment, procedures and programs) used for sale of tickets and control of fare payment.

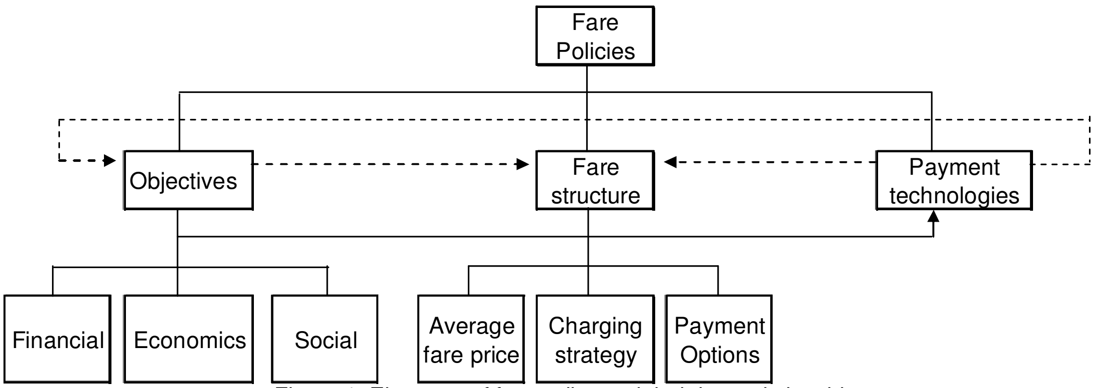

Figure 1: Elements of fare policy and their interrelationships

Source: Novas Tendências em política tarifária – Associação Nacional de Empresas de Transportes Urbanos do Brasil.

There are three basic objectives of fare policies:

a) Financial: to cover the cost of services;
b) Economic: to induce economically optimal user choices;
c) Social: to redistribute income and foster inclusion of less favored classes.

The existence of a mass transit system adequate to the characteristics of the population (in general and riders in particular) and the existing infrastructure is fundamental for the sustainable development of a local economy.

Fare Structure

According to the policy guidebook on fare structures from the Institute for Transport Studies, University of Leeds, available from the Knowledgebase on Sustainable Urban Land Use and Transport (KonSULT), fare structures are important policy instruments because of their potential impact on:

- Efficiency: If a fare structure encourages transfers from cars, then it will affect traffic congestion and increase efficiency of labor markets due to increased access to jobs and possible reduction in unproductive travel time.
- Livable streets: Reduced traffic levels make streets more livable.
- Protection of the environment: Reduced levels of local traffic cut air and noise pollution, put less pressure on natural resources such as oil and green space and reduce greenhouse gas emissions.
- Equity and social inclusion: Fare structures can impact the affordability of public transport and improve access to key goods and services by socially excluded and less well-off citizens.

- Safety: Traveling by public transport is much safer than by car for passengers and also reduces the number of accidents suffered by pedestrians and cyclists.
- Economic growth: If a fare structure encourages transfers from cars, then reduced traffic congestion can stimulate economic growth and improve access to jobs.
- Finance: Fare structures can have a significant impact on revenues and also on costs because they can influence the level of capacity required.

The fare structure is composed of three elements, which combined define the bases for charging for transportation services. They are:

- Average fare price: the method to determine fares and the procedures for their adjustments over time (in this work we do not consider this aspect).
- Charging strategy: falling basically into two categories – unified and diversified, in the latter case considering questions of integration, discounts and free passes.
- Payment options: conditions offered to users to pay fares (single ticket, prepaid electronic card, postpaid billing, etc.).

Charging strategies

The charging strategies are basically divided into two fare structure categories: unified and diversified.

A unified fare is a single price for any trip in a transportation network. A diversified fare structure means there are different prices depending on the type of user, quality of service, trip length and/or travel timing.

According to the American Transportation Research Board (TRB) and the National Association of Urban Transport Companies of Brazil, the different types of strategies can be summarized as follows:

a) Flat fare: a single fare is charged for any trip within the transport network.
b) Distance or zone: different fares are charged according to the distance traveled or number of zones covered.
c) Market: the use of unlimited, weekly, monthly or annual passes, establishing a frequency of use.
d) Time: the fare is different depending on the time of day (peak versus off-peak hours) or on weekends and holidays.
e) Service: the fare is different depending on the type of transport utilized (such as bus or train) or according to the speed (normal versus express).

Table 1 shows the main advantages and disadvantages of each fare system, as pointed out by Pitcher and Tesche (2003).

Table 1: Advantages and disadvantages of fare strategies

Fare Strategy Options		**Advantages**	**Disadvantages**
Flat Fare	**Flat Fare**	Easiest to understand	Places inquitable burden on those making short trips.
		Simpliest and least expensive to implement and administer	Increase will cause greatest loss of riders
		Lowest level of fare abuse	
Differentiated Fare	**Distance/ Zone-Based**	Should produce greatest revenue	Difficult to use
			Difficult to implement and administer;may require special equipment.
		Considered equitable; longer trip has higher cost.	Potentially high level of fare abuse.
			May be unpopular with users with long trips.
	Market-Based	Generally considered equitable;offers ability to pay less.	Generally produces least revenue.
		Can minimize ridership loss with fare increase.	Potentially high level of fare abuse
		Maximizes prepayment.	Requires extensive marketing to maximize ridership.
		Most convenient option.	Highest media production and distribution cost.
	Time-Based	Should increase ridership	Potential for conflicts with drivers
		Allows management of fleet usage through shift to off-peak.	Potential for fraud (agents on rail)
		Considered equitable; commuters pay more.	May require equipment modifications (or new equipment)
	Service-Based	Relatively easy to understand.	May be unpopular among users of higher cost service.
		Considered equitable; higher quality or higher priced service has higher cost	
		High revenue potential; low fare abuse	Complicates transfers (e.g, may require payment of "upgrade" fare in transferring).
		Allows managment of fleet usage through shift between services.	

Source: TRB Transportation Research Board - Fare Policies, Structures and Technologies.Objectives of Fare Policies

Payment options

A variety of payment options are available, the number of which has increased with advances in information technology. The most common options are:

a) Single ticket: This scheme entitles the user to one trip or access to an integrated transport system. Generally the unit price is more expensive.
b) Multiple ticket: This scheme entitles users to several trips or accesses to an integrated system. The initial outlay is higher but the unit price is generally lower because of the number of rides acquired.
c) Time pass: This entails magnetic tickets or smart cards (with chips) allowing an unlimited number of trips within a defined period (month, week, day or number of hours). It can also consider complementary payment in case of transfer between transport modes (e.g., bus to subway) or trips between different areas of a greater metropolitan region.
d) Prepaid credit: In this case the smart card is loaded with a determined fare value and the fare is deducted from the balance each time it is used. The option is most suitable for system with differentiated fares.
e) Postpaid service: The use is monitored by a smart card and billed afterward through an account sent to the user's residence or office.

ANALYSIS OF THE FARE SYSTEM OF SOME METROPOLITAN REGIONS IN NORTH AMERICA, SOUTH AMERICA, EUROPE, ASIA AND OCEANIA.

We obtained the data for this study by research of the literature and databases on the socioeconomic aspects and transportation systems of certain locations, chosen according to the cultural, political and economic importance of the regions and our experiences from studying some of the cities selected.

For each location (metropolitan region) selected, we gathered the following data:

a) Population.
b) Area.
c) Demographic density.
d) Transportation system, including extension, number of lines, number of vehicles and number of passengers carried.
e) Fare integration (total, partial or none).
f) Predominant fare system.
g) Average per capita income in the region (according to the exchange rate of the region's currency with the U.S. dollar on December 29th of the year for which the information was obtained).
h) Basic fare, determined by the weighted average between the number of passengers and the respective fare (passengers1 * fare1 + passengers2 * fare2 / passengers1 + passengers2). In this case we considered one month of use, so for cities without a fully integrated system we considered a single fare for each transport system, and

then calculated the weighted average, multiplied by 44 (considering that a typical month has 22 work days and most users commute to and from work each day, making two trips. In these cases, we used the exchange rate with the dollar of July 1, 2008.

i) $\%_{tr}$, an indicator we created to reflect the relative cost of public transportation to riders' budgets, percentage calculated as the weighted average monthly fare divided by average monthly per capita income in the region.

We chose metropolitan regions in developed and developing countries of North America, South America, Europe, Asia and Oceania, namely: Federal District of Mexico (Mexico), New York-New Jersey Metropolitan Region (United States), Recife Metropolitan Region (Brazil), City of Santiago (Chile), São Paulo Metropolitan Region (Brazil), Brussels Capital Region (Belgium), Greater London (England), City of Madrid (Spain), City of Moscow (Russia), Ile-de-France or Greater Paris (France), Porto Metropolitan Area (Portugal), Melbourne Metropolitan Area (Australia), Seoul Metropolitan Area (South Korea) and the City of Tokyo (Japan).

The next item presents the considerations on all the data gathered on each location and comparisons with the others selected. We should stress the difficulty of standardizing the areas chosen for comparison and harmonization of political divisions and urban areas with the transit systems.

Analysis of the main characteristics of each region

Some observations are possible from analysis of the data on each region chosen.

Comparison of the area covered and tracked transport systems shows that in 78% of the regions with area greater than 1,000 km^2 a tracked system (commuter train/trolley, subway and light rail transit – LRT) carries the most passengers. The only regions where tracked systems do not carry more passengers than other systems are in South America: the São Paulo and Recife Metropolitan Regions. In both, buses are responsible for carrying most of the passengers. For regions greater than 5,000 km^2, 75% have a tracked system that accounts for most passengers carried, except São Paulo.

Analysis of the regions by population shows that 88% of those with more than 5 million people have a subway covering more than 100 km. Only the São Paulo Metropolitan Region does not meet this criterion, while the Mexico Federal District, also in a developing country in Latin America, does have a subway extending more than 100 km.

Comparison of the population density and tracked network extension shows that the regions with more than 5,000 people/km^2 have a system covering more than 100 km and places with densities greater than 9,000 people/km^2 have a system extending more than 500 km.

With respect to fare integration and the fare system, the Federal District of Mexico is the only region that does not have fare integration, instead using a service-based system. All the regions in Europe (where a zone-based system predominates) have total fare integration. The places that have partial fare integration have a distance-based system (Tokyo) or a flat fare (São Paulo and New York-New Jersey).

In relation to average per capita income, 74% of selected regions have a per capita income exceeding US$ 1,000 and 100% of these regions are located in developed countries. All the cities observed in developing countries have less than US$ 1,000 as an average per capita income.

The regions that have $\%_{TR}$ less than 2% are located in New York-New Jersey Metropolitan Region, Seoul and Tokyo. Between 2% to 6% we observe European regions and Melbourne and more than 6% of $\%_{TR}$ the Latin-America regions, precisely those with inferior average per capita income.

In general, Latin American regions do not follow the concept of a transportation network encompassing all systems. Instead, the systems are independent, with occasional initiatives to integrate certain bus routes with subways or commuter trains, and there is not a single entity responsible for planning and operating the network and determining minimum service criteria.

Table 2 summarizes the characteristics of the regions analyzed.

Table 2: Characteristics of the regions analyzed

Location	Area (km^2)	Pop. (mi) 2006	Demog. density (inhab/km^2)	Transp. system	Existing transport system				Fare integration?	Predominant fare system	Average per capita income (US$)	Basic Fare[#] (US$)	$\%_{TR}$
					Ext. (km)	No. of lines	No. of vehicles	No. of passengers carried (year - million)					
Mexico City (DF)	1479.0	8.8	5,965	Bus	3,519.7	89	1,166	290.9	None	Service	135.72	8.36[a]	6.16
				Subway	176.8	11	355	1,417.0					
				Trolleybus	453.1	17	330						
				LRT	n.a.	1	16	62.9					
New York - New Jersey metropolitan area	10,101.0	8,0	1,700	Bus	8,998.4	553	n.a.	1,010.9	Partial	Flat Fare	4,050.00	76.97 [b]	1.90
				Subway	368,0	27	6,494	1,499.0					
				Train	2,688.9	n.a.	n.a.	221.7					
				LRT	67.8	n.a.	n.a.	16.4					
Recife metropolitan area	2,768.0	3.7	1,320	Bus	n.a.	354	2,700	436.7	Total	Zone	400.00	37.40	9.35
				Subway	29.3	3	n.a.	69.3					
				Train	31.5	1	n.a.	n.a.					
Santiago	876.8	4.6[p]	5,324	Bus	n.a.	n.a.	4,654[s]	n.a.	Total	Flat Fare	551.47	36.08[c]	6.54
				Subway	84.4	5	n.a.	330.0					
				Train	65	n.a.	n.a.	n.a.					
São Paulo Metropolitan area	8,051.0	19.7	2,450	Bus	n.a.	1,860	18,761	3,033.8	Partial	Flat Fare	711.44 [s]	68.64[d]	9.65
				Subway [s]	61.3	4	702 [t]	611.0					
				Train	257.5	6	110	584.0					
Brussels Capital region	241.5	1.1 [o]	4,555	Bus	420.4	47	598	76.1	Total	Flat Fare	1,115.30 [r]	65.51[e]	5.87
				Subway	49.9	3	90	122.5					
				Tram	217.3	18	311	70.8					
				Train	72.5	n.a.	n.a.	n.a.					
Greater London	1,579.0	7.5	4,758	Bus	n.a.	700	8,000	1,168.0	Total	Zone	4,233.38	185.44[f]	4.38
				Subway	408.0	12	4,070	1,014.0					
				Tram	28.0	3	24	n.a.					
				DLR	31.0	n.a.	94	61.3					
				Train	788.0	n.a.	n.a.	232.0					
Madrid	604.3	3.2	5,304	Bus	3,485.0	204	2,022	490.6	Total	Zone	1,700.40 [r]	63.85 [g]	3.75
				Subway/VLT	220.0	13	n.a.	657.4					
				Train	101.0	n.a.	n.a.	n.a.					
Moscow	1081.0	10.44	9,660	Bus	15,044.1	1.247	10,499	1,882.9	Partial	Flat Fare	1,244.16[o]	55.42[h]	4.45
				Subway	278.8	13 [r]	n.a.	2,475.6					
				Trolleybus	940.6	85	1,601	465.5					
				Tram	415.1	38	917	275.0					
				Train	782.1	n.a.	n.a.	605.6					
Ile-de-France[q]	12,012.0	11.49[q]	957	Train	1411.0	7	4,87	1,051.8	Total	Zone	2,885.20 [r]	86.98[i]	3.01
				Subway	211.3	16	3,553	1,335.7					
				Tramway	23.5	2	235	44.1					
				Bus	22,820.6	1.334	4,064	1,191.0					
Porto metropolitan area	814.5	1.27	1,571	Bus	496.0	94	508	190.0	Total	Zone	1,109.70 [r]	37.08 [j]	3.34
				Subway	58.9	5	n.a.	38.6					
				Train	35.5	n.a.	n.a.	n.a.					
Melbourne metropolitan area	8,097.2	3.59	443	Bus	n.a.	314	1,472	80.0	Total	Zone	1,853.7	99.51[k]	5.37
				Tram	249.0	27	499	155.0					
				Train[s]	382.0	15	329 [v]	162.0					
Seoul metropolitan area	605.0	10.29p	17,019	Bus	n.a.	n.a.	n.a.	1,699.0	Total	Distance	2,139.70 [r]	33.51[m]	1.57
				Subway	286.9	8	399	2,023.8					
				Train	246.0	n.a.	n.a.	704.5					
Tokyo city	621.05	8.57	13,720	Bus	779.0	138	1,467	206.0	Partial	Distance	4,856.8	78.76[n]	1.62
				Subway	289.4	12	n.a.	2,929.8					
				Train	310.6	n.a.	n.a.	2,681.9					

&- $\%_{TR}$ Percentage calculated as the weighted average monthly fare divided by average monthly per capita income.
n.a.- Not available.
#- Rate for the year 2008.
a- 44*weighted price.
b- Rate for one month.
c- 44 Tickets at peak time.
d- 44*weighted price.
e- Unlimited monthly pass.
f- Unlimited monthly pass (Zona 1 and 2).
g- Unlimited monthly pass (Zona 1 and 2).
h- Unlimited monthly pass - subway.
i- Unlimited monthly pass (Zona 1 and 2).
j- Unlimited monthly pass (Zona 1 and 2).
k- Unlimited monthly pass (Zona 1).
m- Unlimited monthly pass (distance - 10 km).
n- 44*weighted price (from 7-11Km).
o- Data from 2000.
p- Data from 2002.
q- Data from 2004.
r- Data from 2005.
s- Data from 2007.
t- Each train has 6 cars.
u- With monorail.
v- Trains has 3 cars.

The characteristics of selected regions (Table 2) together with the literature review, contributed to the choice of Analytic Hierarchy Process, and consequently criteria and sub-criteria selection.

METHODOLOGY

We applied the Analytic Hierarchy Process (AHP) to determine the best fare system in a region.

Concept

We chose the Analytic Hierarchy Process because it is a multi-criterion technique to assist in making decisions that uses a structure of networks or hierarchies to represent a problem and establishes a ranking of the possible actions based on the judgment of the decision maker (or makers). It was developed by Thomas L. Saaty in the mid-1970s.

The process is based on decomposing and synthesizing the relationships of the criteria until attaining a ranking of their indicators that approximates the best response of a single performance measure (Saaty, 1987).

Hierarchic structure

When faced with a problem of comparing among various elements of a set, the human mind creates a process of ranking. Based on this, AHP is a method where the problem under analysis is structured in a hierarchy, where the highest level is the main objective of the study, the next levels are the criteria (properties by which the alternatives are evaluated) and the lowest level contains the alternatives to be compared. Figure 2 below presents a simplified representation of this hierarchical structure.

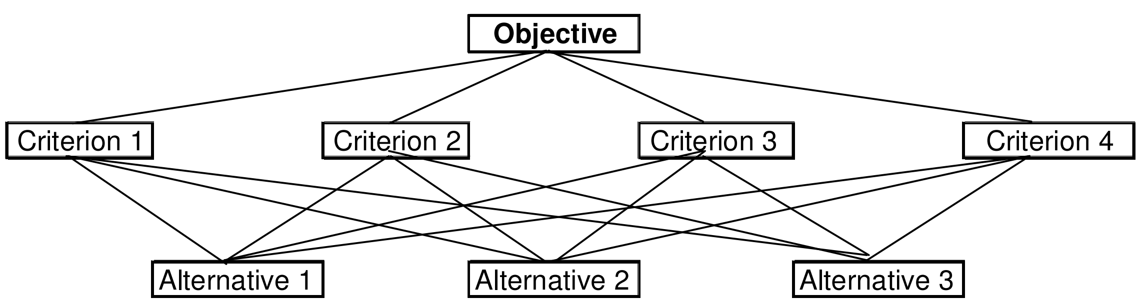

Figure 2: Hierarchic structure levels

The step of structuring the problem and constructing the hierarchy is very important, because it serves as the basis for comparing the criteria and then the alternatives.

Description of the Analytic Hierarchy Process

The AHP permits attributing weights where numerical values cannot be obtained directly. It therefore works with a comparison matrix to evaluate the importance of a particular characteristic in relation to another, utilizing a suitable scale (Saaty, 1987).

The comparison matrix is constructed so that the specialist first makes a pairwise analysis of the attributes according to their level of importance. The same analysis is them carried out with the items (alternatives) in relation to each attribute separately, to finally obtain a ranking of the alternatives in order of importance.

The scale recommended by Saaty (1987) goes from 1 to 9, with 1 meaning indifference as to the importance of one criterion over the other and 9 meaning one criterion is extremely important in relation to the other, with intermediate importance levels between these extremes. The comparisons between the same criteria, which represent 1 on the scale, are disregarded, leaving only half the comparisons, because the other half are reciprocal comparisons in the matrix.

The judgment of importance reflects two questions: Which of the two elements is more important with respect to a higher level criterion, and with what intensity on the 1-9 scale?

Development of the Analytic Hierarchy Process

Determination of the objectives, criteria and alternatives

Our objective here is to determine, based on the factors established, the best fare system and the most important factors in each system. The fare systems chosen are those already mentioned.

The criteria were established based on the judgments of the main agents involved in the system, that is, government, operators and users, on the main objectives of a fare policy and on the characteristics of the regions analyzed.

The criteria and sub-criteria that were analyzed for each fare system are (Figure 3):

1) Complexity: Involving the simplicity and ease of understanding the fare system, based on the number of options and price levels available and the degree of difficulty in differentiating them.
Sub-criteria: a) Number of payment forms.
b) Information about the system.

2) Impact on revenues: The ability to increase revenues (e.g., increased number of trips) or reduce the operator's costs (e.g., reduced administrative/operating overhead).
Sub-criteria: c) Reduction of administrative/operating overhead.
d) Increase in number of riders.

3) Control of passengers: Ability to minimize evasion or abuse by passengers (e.g., underpayment of the fare or turnstile jumping), by the use of equipment and software.
Sub-criteria: e) Equipment used in each fare system.

f) Use of software.

4) Difficulty of implementation: The difficulty of implementing the fare system due to the lack of integration among operators and/or regulators of various means of transport.
Sub-criteria: g) Difficulty of integration of the various operators.
h) Difficulty of integration of the various regulators.

5) Long trips: The impact of the fare system on the number of long trips, considering the extension of the existing transit network, number of long trips and population density around the downtown area.
Sub-criteria: i) Extension of the network.
j) Number of long trips.
k) Population density surrounding the downtown area.

6) Forms of payment: The ability to reduce the use of cash for each trip by increasing the use of prepayment schemes.

7) Fare price: Achievement of a balance between the fare price and user mobility cost, considering the average income of the population.

8) Cost of implementation: The total cost of implementing the fare system in a region, considering the number of users.

9) Number of trips: The increase in the number of trips taken in the transport system due principally to the fare value and cost-benefit ratio of the service offered.
Sub-criteria: l) Service offered for the fare price paid.
m) Fare price.

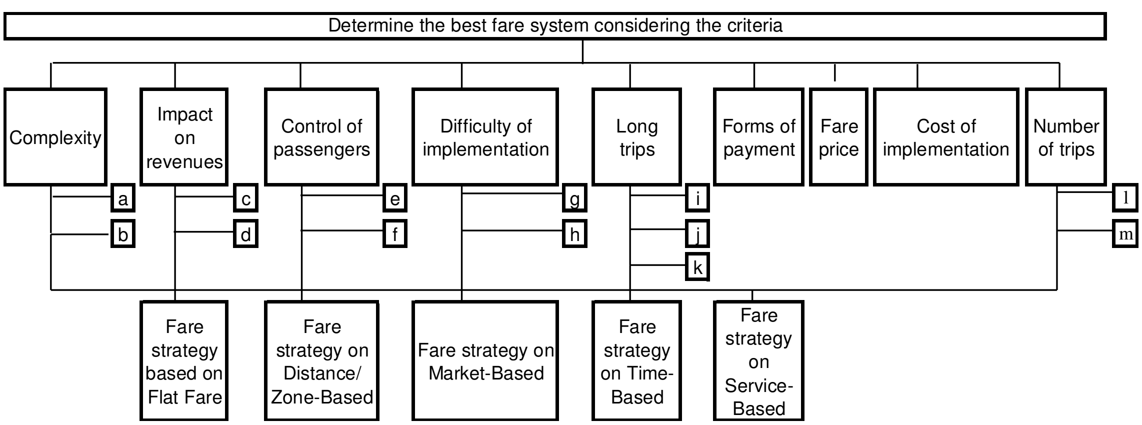

Figure 3: Hierarchical structure for analysis of the fare system

Selection of the specialists:

We chose 21 specialists with extensive experience in transportation issues, divided into three groups: operators, professors/consultants and government officials.

These specialists completed a questionnaire in the form of Microsoft Excel spreadsheets.

Expert Choice

We analyzed the specialists' responses using the Expert Choice 2000 program, from Expert Choice Inc. It is a program to support decision making that permits constructing evaluation and choice models, based on hierarchical analysis, to facilitate analysis, synthesis and justification of decisions.

Questionnaires

We prepared the questionnaires according to the pairwise comparison matrices in an Excel file. We sent the files to the specialists by email. The questionnaires were formulated so that after each matrix was filled out, a consistency ratio was calculated (the lower the ratio the more consistent the responses), to indicate whether any revision in the judgments was necessary due to inconsistency. When the inconsistency was greater than 0.10, the experts were asked to revise their judgments to reduce this ratio.

RESULTS

The results obtained by applying the Expert Choice program are divided below into four analyses, according to the operators, professors/consultants, government officials and a combination of the results of those three groups.

Operators

The seven experts in this category were chosen from among public transit operators in both the private and public sectors.

According to their opinion, the criteria have the following order of importance: impact on revenues (23.9%), fare price (18.8%), control of passengers (13.0%), cost of implementation (10.8%), long trips (7.8%), forms of payment (7.7%), number of trips (7.0%), difficulty of implementation (5.9%) and complexity (5.1%). It can be seen, then, that operators place the greatest importance on revenues to determine the best fare system.

The calculation of the matrices resulted in a ranking where zone or distance is the best system according to the criteria established (33.0%), followed by a service-based fare system (24.5%), market-based system (17.4%), time-based system (17.0%) and flat fare system (8.1%).

Therefore, according to the operators, a system with diversified fares is the best. Figure 4 shows the results obtained for each alternative, criterion and sub-criterion.

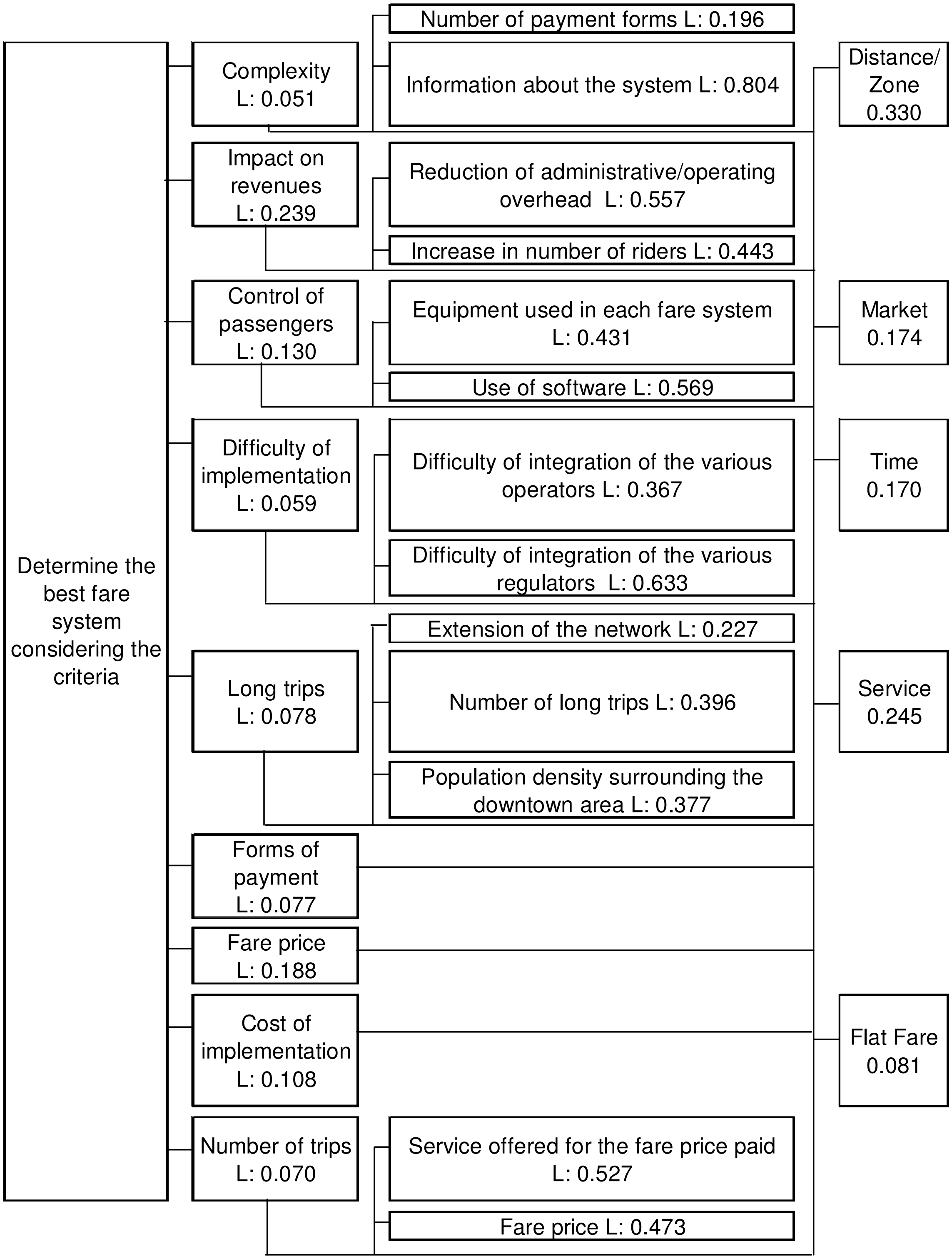

Figure 4: Result – Operators

Professors/Consultants

The seven professors/consultants questioned are based in the states of Rio de Janeiro and São Paulo and work at public universities in these states.

According to their opinion, the criteria appear in the following order of importance: fare price (22.6%), cost of implementation (18.9%), impact on revenues (10.7%), number of trips (10.6%), difficulty of implementation (10.6%), control of passengers (10.1%), forms of payment (6.9%), complexity (5.1%) and long trips (4.5%). As can be seen, the professors/consultants place greatest emphasis on the fare price.

The calculation of the matrices resulted in a ranking where the best system according to the criteria established is that based on distance or zone (31.1%), followed by a market-based system (23.3%), time-based system (20.5%), service-based system (19.7%) and flat fare system (5.4%).

Therefore, according to the academics, a fare system based on a diversified fare structure is the best. Figure 5 presents the results obtained for each alternative, criterion and sub-criterion.

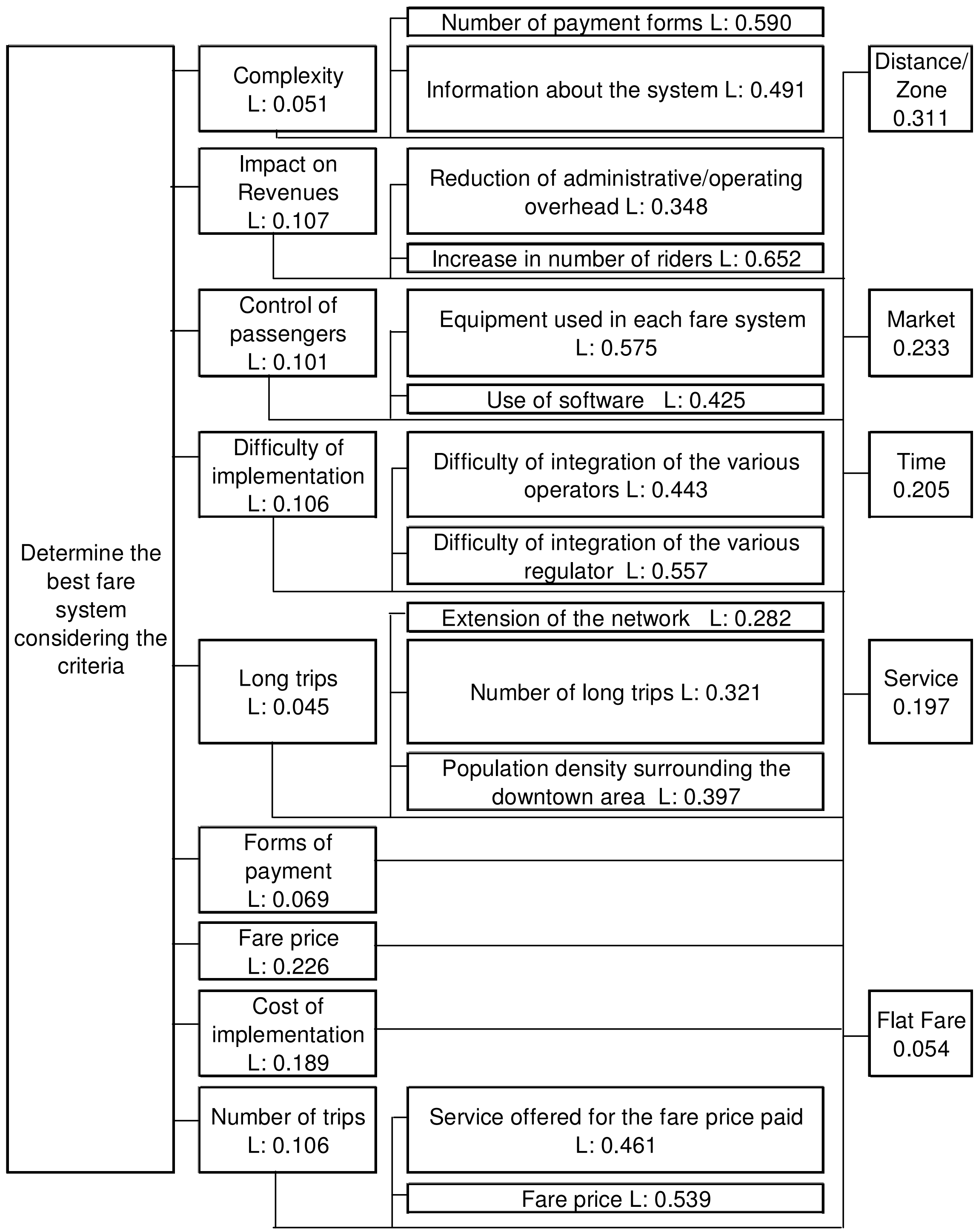

Figure 5: Result – Professors/Consultants

Government Officials

The seven people chosen from the public sector work in government agencies at the municipal, state or federal level in three Brazilian cities: São Paulo, Rio de Janeiro and Recife.

According to their opinion, the criteria appear in the following order of importance: fare price (20.5%), number of trips (14.6%), control of passengers (12.2%), complexity (11.9%), impact on revenues (11.5%), long trips (9.9%), forms of payment (8.4%), cost of implementation (5.7%) and difficulty of implementation (5.3%). As among the academics, the public officials also believe the fare price is the most important factor in determining the best fare system.

As shown in Figure 6, the government officials also believe a fare system based on distance or zone is best (28.8%) according to the criteria established, followed by service (23.6%), market (20.6%), time (18.5%) and flat fare (8.5%).

Therefore, according to the government officials surveyed, a diversified fare system is best. Figure 6 shows the results obtained for each alternative, criterion and sub-criterion.

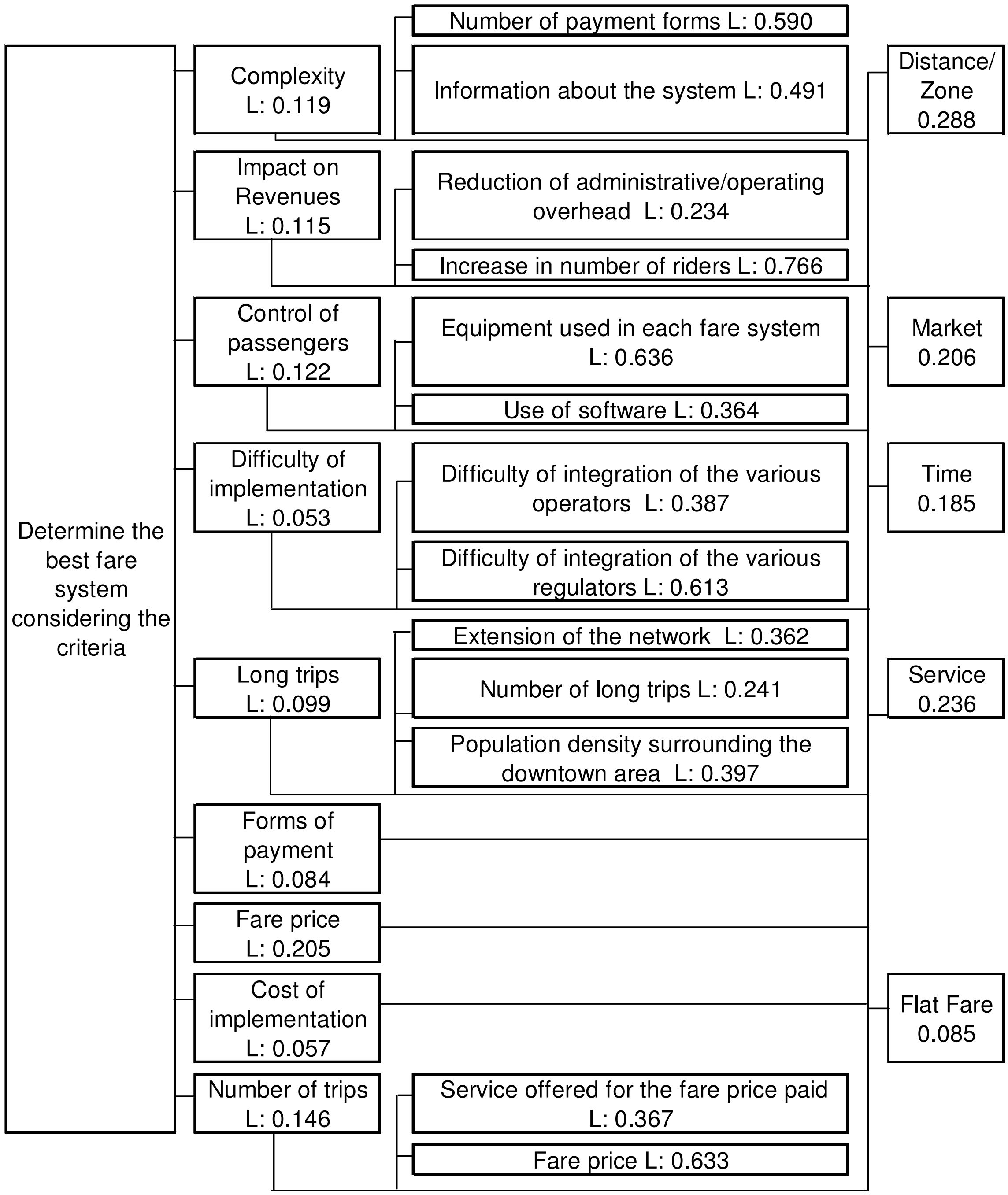

Figure 6: Result – Government Officials

Combination of the results of the three groups: operators, professors/consultants and government officials

According to the results of the three groups together, the criteria appear in the following order of importance: fare price (21.5%), impact on revenues (14.9%), control of passengers (12.2%), cost of implementation (11.0%), number of trips (10.8%), forms of payment (8.0%), long trips (7.4%), difficulty of implementation (7.2%) and complexity (7.0%). As is the case for two of the three groups, fare price is considered the most important in determining the best fare system, in the view of specialists in a developing country.

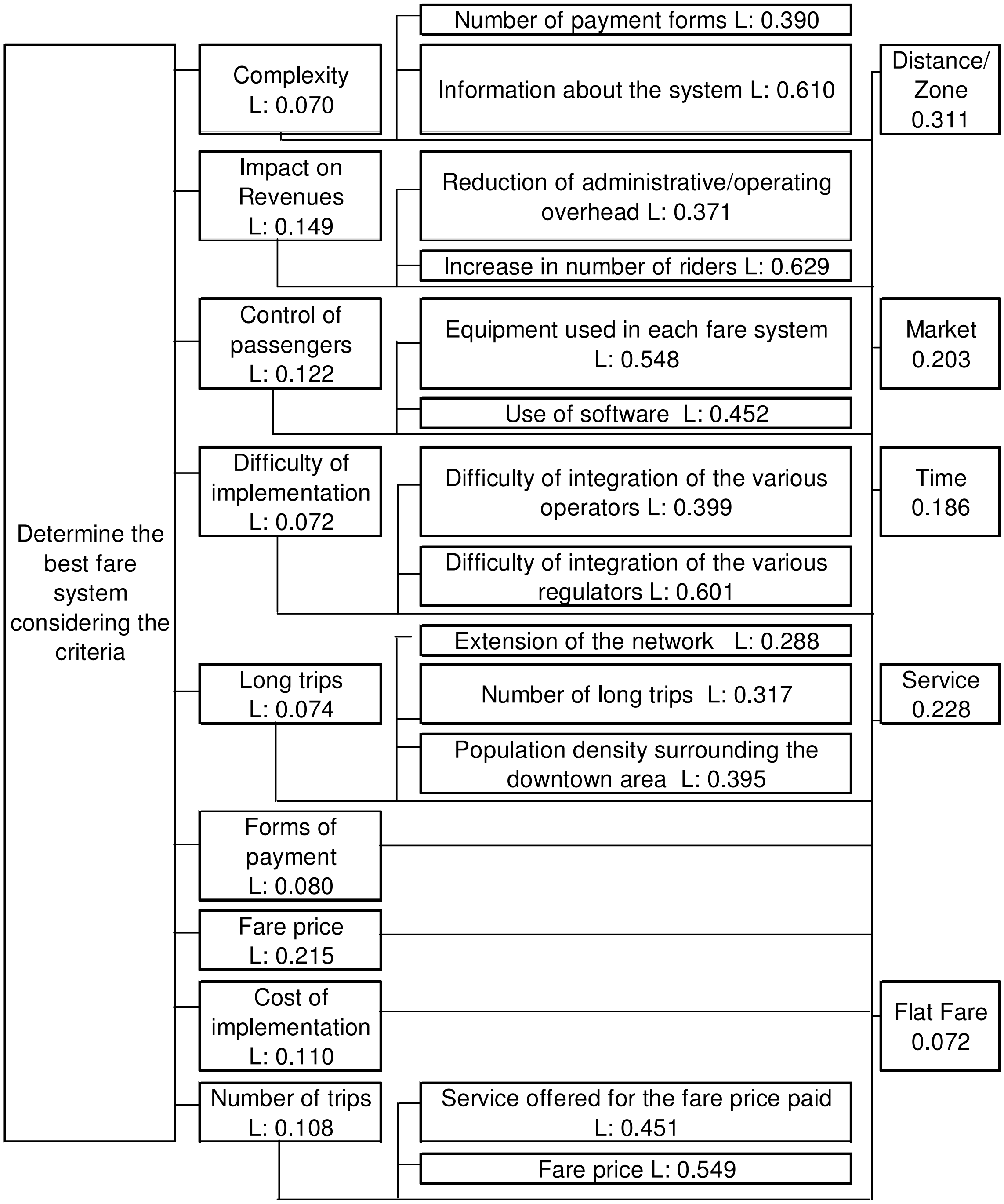

Figure 7: Result – Final

As shown in Figure 7, the combined opinion of the three groups is that a fare system based on zone or distance is the best (31.1%) according to the criteria established, followed by a service-based system (22.8%), market-based system (20.3%), time-based system (18.6%)

and flat fare system (7.2%). Therefore, according to all the experts taken together, a diversified fare structure is best.

It is interesting to note that the order of the alternatives defined by the operators and government officials was the same. Also, the academics' opinions only differed from that of the other experts in relation to the order of the middle three fare systems. The highest and lowest ranked fare systems were the same for all three groups chosen (Table 3).

Table 3: Comparison of the results – Fare system

Ranking	**Operators**	**Professors/ Consultants**	**Government Officials**	**Final**
1	Distance/Zone (33.0%)	Distance/Zone (31.1%)	Distance/Zone (28.8%)	Distance/Zone (31.1%)
2	Service (24.5%)	Market (23.3%)	Service (23.6%)	Service (22.8%)
3	Market (17.4%)	Time (20.5%)	Market (20.6%)	Market (20.3%)
4	Time (17.0%)	Service (19.7%)	Time (18.5%)	Time (18.6%)
5	Flat Fare (8.1%)	Flat Fare (5.4%)	Flat Fare (8.5%)	Flat Fare (7.2%)

A comparison of the results of each group with respect to the criteria (Table 4 below) shows that the operators and academics give equal importance to the complexity criterion. Also, the academics and government officials give almost the same importance to the impact on revenues criterion, which has half the percentage as that attributed by the operators.

The operators and public officials give almost the same importance to the difficulty of implementation criterion, assigning it half the percentage importance as the professors/consultants. The same occurs even more markedly in relation to long trips, in which the importance to the academics is only one-half that given by government officials and 73% more by the operators. This reflects the vision of public officials of the need to subsidize mass transit for low-income people, who in developing countries typically live on the periphery of cities and need to travel farther to their jobs.

The level of importance of the cost of implementation criterion evidences the small importance public officials attach to it, in contrast to the operators (who rate it as having twice the importance) and the academics (who rate it as having three times the importance). This indicates that for public authorities, the cost of implementation does not play a big role in reaching a decision on which fare system to adopt. In this respect, we should note that because Brazil is a developing country that needs large investments to improve the quality of life, the adoption of a fare system that combines a low cost of implementation with efficiency and efficacy is fundamental.

In relation to the number of trips criterion, the percentage of importance given by the operators is half that assigned by the public officials.

The importance attached to the long trips, number of trips and fare price criteria by the public officials shows the need for public policies that prioritize transport of more people, especially those with lower purchasing power (who generally live farther from job centers).

In general, the experts consider the impact on revenues and fare price criteria as most important for definition of a fare system.

Table 4: Comparison of the results – Criteria

Criterion	Operators	Professors/ Consultants	Government Officials	Final
Complexity	5.1%	5.1%	11.9%	7.0%
Impact on revenues	23.9%	10.7%	11.5%	14.9%
Control of passengers	13,0%	10.1%	12.2%	12.2%
Difficulty of implementation	5.9%	10.6%	5.3%	7.2%
Long trips	7.8%	4.5%	9.9%	7.4%
Forms of payment	7.7%	6.9%	8.4%	8.0%
Fare price	18.8%	22.6%	20.5%	21.5%
Cost of implementation	10.8%	18.9%	5.7%	11.0%
Number of trips	7.0%	10.6%	14.6%	10.8%

Analysis of the sub-criteria (table 5) shows that the number of forms of payment and information on the system (related to the complexity criterion) and reduction of administrative/operating overhead and increase in the number of users (related to the impact on revenues criterion) have the same degree of importance for the academics and government officials. With respect to the difficulty of integrating various operators and difficulty of integrating various regulators sub-criteria (related to the difficulty of implementation criterion), the operators and public officials attach practically the same level of importance.

Table 5: Comparison of the results – Sub-criteria

Criterion	Sub-criteria	Operators	Professors/ Consultants	Government Officials	Final
Complexity	Number of payment forms	19.6%	59.0%	59.0%	39.0%
	Information about the system	80.4%	49.1%	49.1%	61.0%
Impact on revenues	Reduction of administrative/operating overhead	55.7%	34.8%	23.4%	37.1%
	Increase in number of riders	44.3%	65.2%	76.6%	62.9%
Control of passengers	Equipment used in each fare system	43.1%	57.5%	63.6%	54.8%
	Use of software	56.9%	42.5%	36.4%	45.2%
Difficulty of implementation	Difficulty of integration of the various operators	36.7%	44.3%	38.7%	39.9%
	Difficulty of integration of the various regulators	63.3%	55.7%	61.3%	60.1%
Long trips	Extension of the network	22.7%	28.2%	36.2%	28.8%
	Number of long trips	39.6%	32.1%	24.1%	31.7%
	Population density surrounding the downtown area	37.7%	39.7%	30.7%	39.5%
Number of trips	Service offered for the fare price paid	52.7%	46.1%	36.7%	45.1%
	Fare price	47.3%	53.9%	63.3%	54.9%

With respect to the complexity criterion, the operators and academics attach the same importance, but for that criterion's sub-criteria (number of forms of payment and information on the system), it is the academics and public officials that agree. Note that for the operators, the information on the system sub-criterion is far more important than the number of payment forms in the complexity criterion, something that does not occur among the academics and government officials.

Regarding the impact on revenues and complexity criterion, the professors/consultants and public officials attach the same importance. For the academics and government officials, reduction of administrative/operating overhead has the same importance, less than that in the operators' opinion. With respect to the increase in number of riders sub-criterion, the academics and public officials attach the same importance, higher than that assigned by the operators.

Sensitivity analysis

There are various methods of sensitivity analysis to determine how changes in one or more criteria affect alternatives or outcomes. In this study we used gradient sensitivity analysis.

Figure 8 shows the variation of the fare system according to the variation of the impact on revenues criterion, according to this analysis.

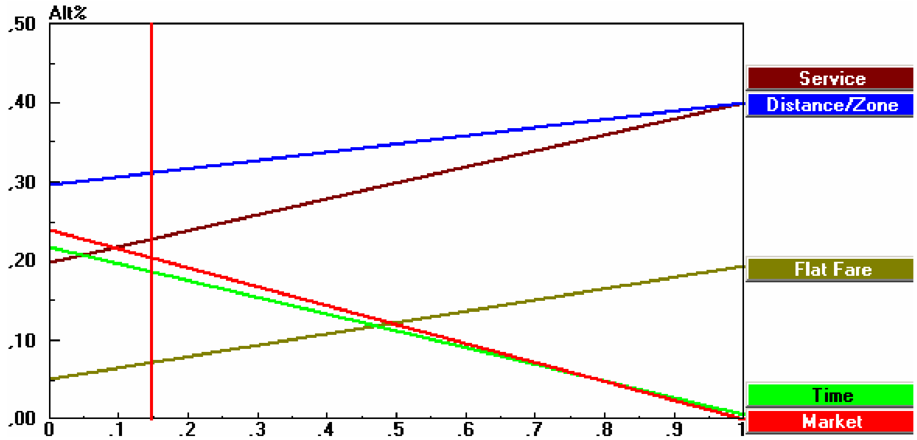

Figure 8: Criterion: Impact on revenues - Result – Final.

The result presented in Figure 8 shows that an increase of the impact on revenues criterion (to a 98% degree of importance) would result in choosing a service-based system as best, followed by a distance/zone system.

Figure 9 shows the variation of the fare system according to the variation of the fare price criterion through the same sensitivity analysis. This criterion was selected as the most important by all the experts, with 21.5%.

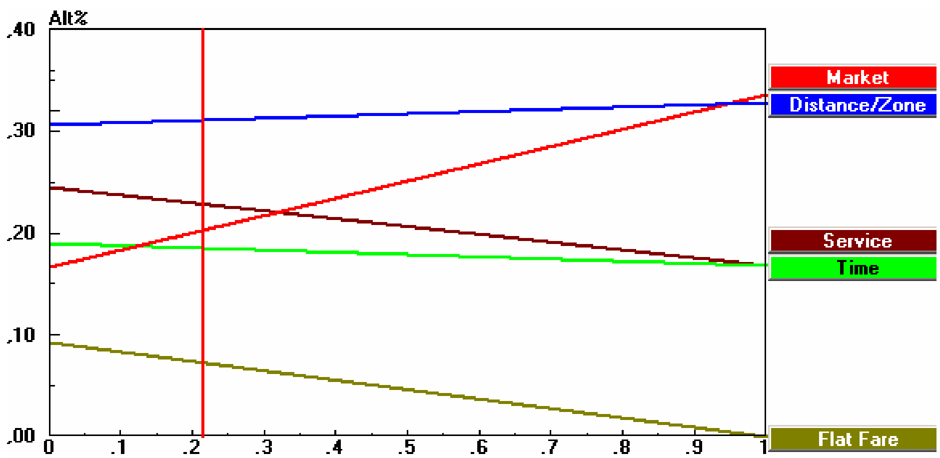

Figure 9: Criterion: Fare price - Result – Final.

The vertical red line in Figure 9 represents the value of the fare price criterion. By increasing or decreasing this value (on the x-axis), the order of importance of the systems changes.

Analysis of the result shown in Figure 9 shows that in increase in the fare price criterion does not change the best choice from the distance/zone system until it reaches an importance of

95%, after which the market-based system becomes the best. Indeed, the other three systems decline in importance as the fare price criterion increases.

Therefore, according to the specialists consulted for this study, the best fare system considering the criteria established is that based on distance or zone.

CONCLUSIONS

The main objective of this article is to determine the best fare system to implement in an area, using the Analytic Hierarchy Process (AHP).

To apply the AHP to this question, we conducted a survey among Brazilian transport specialists, divided into three equal groups, drawn from transport operators, academia and government. We sent an Excel questionnaire by email, containing pairwise matrices allowing them to present their relative judgments of the following criteria: complexity, impact on revenues, control of passengers, difficulty of implementation, long trips, forms of payment, fare price, cost of implementation and number of trips, and the respective sub-criteria: number of payment forms, information on the system, equipment used in each fare system, use of software, difficulty of integrating various operators, difficulty of integrating various regulators, extension of the network, number of long trips, population density around downtown, service offered for the fare and fare price.

The general result was that fare price is the most important criterion, with 21.5%. The system determined as the most important was distance/zone (fare diversification) and the least important was a flat fare system.

We should point out that many results presented here demonstrate a typical planning approach in developing countries, with populist actions based on short-term considerations taking precedence over technically based long-term solutions. A comprehensive modification of mobility in metropolitan regions, with the creation of various poles of development and employment, generating new mobility networks, would help alleviate the current problems of an overly centralized system subject to frequent operational failings.

The planning of a fare system coherent with the characteristics of the region affected is crucial to provide greater mobility to the population and enhance regional development.

Brazilian cities are marked by an absence or insufficient scope of tracked systems, and the bus systems are not well planned, besides charging high fares. These drawbacks force a great percentage of people to rely on more than one line and/or form of transport, and to pay multiple fares in their daily commutes.

One cause of this situation is the Brazilian constitution, which provides that authority to organize mass transit services rests with the municipalities. The fact that most large metropolitan regions take in several municipalities, often led by competing political interests, makes total integration of the network and fare system extremely difficult, even though this hinders the population's mobility and the development of the region as a whole. The results of coordinated efforts in the metropolitan areas (or megalopolises) of the other countries analyzed in this article, particularly those in Europe, Asia and North America (but sadly absent in South America), show what can be achieved with careful and rational planning.

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