The analytic hierarchy process to evaluate the quality of service in transit systems

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Abstract

In this work the Analytic Hierarchy Process (AHP) method has been used to evaluate the best action to be performed by a public transit company with reference to a general goal aimed at customer satisfaction. The tested procedure can help the planner to select the most effective action with reference to the general goal by using in optimal way the available resources.
Keywords: public transport, evaluation, Analytic Hierarchy Process, service quality.

1 Introduction

In the last years, different initiatives both at national and European level have been taken in order to increase the share of the public transport and then to resolve many of the problems linked to the excessive use of cars in urban areas.

The actual reorganization of the public transport sector considers the assignment of the service management to a specific company by means of some bidding procedures that allow the public planner to select the best company in terms of technique and organizing requirements that satisfy the planned targets.

In such a context, the monitoring capability of a company in terms of user satisfaction becomes an important element, given that the improvement of the user satisfaction also means the respect of the quality of the offered service and then the acquisition of new users that in turn means an increase of revenue. Then, not only the cost reduction is crucial for the transit company but also an

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organization approach that considers the users at the centre, given that their satisfaction is directly linked to the expected revenue.

In the sphere of the different initiatives that a company can adopt to improve its efficiency and effectiveness, those that guarantee a greater user satisfaction should be preferred, obviously within the boundary of the available financial resources.

Naturally, the satisfaction of users that already use the public transport system cannot be considered the specific target of the company transformation and user-addressed adjustment process, but it should be noticed that the satisfaction of these users represents the basic level from which the company should start to acquire a greater number of potential users possibly coming from other transport systems (above all, the individual transport systems, as cars and motorbikes).

From this point of view, it is important to verify which are the aspects of the offered service that mainly influence the user trip choices, and then which is the user perception of the offered service. To this aim, the more recent technological developments in the telecommunication field can be used, as the user information systems at stops. Such systems should provide a high quantity of information referred to the trip or linked to it (as information referred to tickets sale, scheduled timetable, possible strikes, and so on), and they should be easily combined with other possible Advanced Vehicle Management (AVM) systems already present in the company.

A simple monetary analysis of advantages and disadvantages deriving from the realisation of such systems, however, can be unsatisfactory, but the Analytic Hierarchy Process (AHP) can help the analysts in order to define the cost-benefit ratio. This method can be used to evaluate the priority of possible actions by means of the construction of a dominance hierarchy, i.e. a tree structure formed by two or more layers. The first layer refers to the goal, the general objective of the evaluation process; the second layer refers to different objectives that specify contents and meaning of the goal. The actions to be evaluated are at the base of the hierarchy and are linked directly to the more specific objectives (final objectives). Inside the hierarchy different actors involved in the process can be considered , in order to take into account different points of view depending on the differences in interests and aims.

The purpose of this work is to test on a real case the AHP methodology in order to identify the most appropriate actions that should be undertaken to increase the public transport user satisfaction level. Particularly, the AHP method has been applied to the transit company of the city of Reggio Calabria (South of Italy), in order to verify the priority of the actions with respect to the quality of the offered service and the realization of user information systems.

In the following, section 2 briefly reports the current situation and the tendency in progress within the public transport companies; section 3 describes the muticriteria method used; section 4 reports the application on a test case and, finally, section 5 reports the conclusions.

2 Current scenario in the local public transport sector

The most realistic economic scenarios establish that in the next twenty years the public transport systems will be conditioned by two essential characteristics: protection of the customer (by means of services that can guarantee his/her health and safety) and sustainable development.

With reference to the Calabria administrative region (South of Italy), where the company for which the procedure has been tested is located, the Regional Directives (LR n. 36, 24-12-2004) in accordance with the National and EU directives establish that the public services management will be realized by means of specific contracts to suitable selected companies, and they are intended to guarantee a better quality and reliability of the offered service.

In the last years a lot of transit companies in Italy have chosen to adapt their management system to the UNI EN ISO 9001:2000 rule; this can be considered a strategic choice that mainly aims at the customer satisfaction. Then, users play an important role in the definition of the system requirements and the monitoring of their satisfaction degree is essential to continuously improve the supplied service.

Furthermore, the UNI EN ISO 9001:2000 rule also addresses the company towards a productive system and a service management able to optimize the use of the available resources: the management process should be clearer and checked without ambiguity, both users and control authorities should increase their degree of confidence in the company and, finally, the organizing, managerial and productive system should be more specifically addressed to meet the needs of users and generally of the society.

Furthermore, following the UNI EN ISO 9001:2000 rule, transit companies define effective modalities to inform users about the service; at the same time, all the information provided by users is used in the process, in a continuous feedback.

For a transit company, quality means above all the capability to satisfy some customer needs as regularity, punctuality, low crowding level on board and so on. The capability to satisfy such needs is as more effective and complete as more significant is the underlying degree of satisfaction of the involved parts. This strategic target should be obtained by transit companies by means of two complementary and synergic tools: the process and services optimization, based on research, innovation and technological development; a suitable management and control of all the activities related to the service production.

3 The analytic hierarchy process

The Analytic Hierarchy Process (AHP) is a multicriteria decision support method [1, 2], able to analyse a complex situation by breaking down the problem in more parts and organizing them following a hierarchy, by assigning numerical values to subjective judgments on the relative importance of each variable and finally synthesising the judgments to obtain the global priority of the actions [3]. These actions can be programs, intervention strategies, projects, and so on. The method can be used to determine the benefit/cost ratio when it is not possible to evaluate all the advantages and disadvantages that can derive from its realisation in a simple monetary form.

In the literature there are different examples of AHP applications to evaluation problems in the most different fields [4], particularly in the decisional processes that involve environmental and social aspects, where the most part of costs and benefits belong to the goods category for which the identification of their price is impossible or very complex.

In the following, the general principles of the AHP method will be briefly described. Due to space constraints, the interested reader can refer mainly to [2] and [5] for the axioms and the demonstration of the theorems on which the method is based.

The general problem can be formulated as follows. Given that there are n possible actions to be considered to satisfy a main objective (goal), the actions should be evaluated in a quantitative way on the basis of their relative weight (in terms of importance, priority, size) with respect to each other action. To resolve such a problem by using the AHP method, four main steps described in the following should be considered.

3.1 The dominance hierarchy

The first step (design phase) needs to identify the hierarchy of the problem, i.e. a tree structure should be identified where the root represents the general aim (goal) while the other nodes at lower level represent the criteria used to come to a decision. The final level, the lowest in the hierarchy, is formed by the n alternatives (or actions) among which a choice must be accomplished. Generally, a decision process can involve more actors (e.g., users of the system, society, companies, and so on), and each of them can identify a different order of actions priority with respect to different specific interests. The AHP method is able to consider more actors, even if, for simplicity and lack of space, in this work only one actor has been considered, specifically the transit company.

3.2 The comparison matrix

The second step (evaluation phase) refers to the pair-wise comparison between two nodes of the hierarchy belonging to the same level (depending on the kind of level, such a comparison refers to pairs of criteria or pairs of actions). This comparison considers the contribution provided by the factor that is on the upper level with respect to that under consideration and that, in any case, is linked to the compared factors. The comparison problem can be stated as follows: given two elements, i and j, the decision maker has to establish which is the most important one with respect to a given factor and how much is bigger. To resolve the problem, one can use the evaluations given by some experts that provide directly the preference value of i w.r.t. j (dominance index a_{ij}), but generally the semantic scale [2] or the rating method [6] are used.

With the first method, preferences are expressed in a scale ranging from 1 to 9 [2]; a qualitative judgement is associated to a numerical value as follows:

a_{ij}	*Judgment*
1	equal importance
3	weak importance (of one over the other)
5	strong importance
7	demonstrated importance over the other
9	absolute importance
2, 4, 6, 8	intermediate values between

On the contrary, with the rating method the evaluator can use an available budget of 100 that should be divided between pair of elements to be compared, such that the amount of score assigned to each element (rating) identifies its relative importance. The dominance index a_{ij} is then computed as the ratio of the two elements ratio.

If a perfect consistency of the judgment can be assumed, regardless of the way in which the results are obtained, this means that $a_{ji}= 1/a_{ij}$ and each column of the comparison matrix must be identified by means of independent judgments on each pair of factors. The result of the comparison if a square positive and reciprocal matrix, also called *comparison matrix*, A, whose generic element a_{ij} (the dominance coefficient) represents an estimate of the dominance of the i-th element w.r.t. the j-th element.

The comparison of pairs of n elements provides n^2 coefficients: only $n(n-1)/2$ must be evaluated directly, given that $a_{ii}=1$ and $a_{ji}=1/a_{ij}$ for each di i and j. The second condition, known as *reciprocity property*, needs to guarantee the symmetry of the judgments.

3.3 The evaluation of the local weights

The basic theory is based upon the hypothesis that each a_{ij} is the approximation of the relative weights (w_i/w_j) of the n examined alternatives. The weights are coefficients that measure the relative importance of each element w.r.t. the element belonging to the immediately upper level of the hierarchy. If w_i and w_j are the weights of the generic elements i and j, in an ideal situation the generic element a_{ij} of the comparison matrix should be given by the ratio w_i/w_j for each i and j. In this case the matrix is called consistent and satisfies the condition $a_{ij}=a_{ik}\cdot a_{kj}$ for each i, j and k; then, the weights can be univocally evaluated by fixing to 1 the value of an arbitrary chosen weight or by imposing that their sum must be equal to 1.

Generally, the judgments provided do not assure the consistency of the comparison matrix; the lack of consistency depends both on the difficulty to maintain the coherence of the judgments for all the comparisons between pairs of elements and on the fact that the judgments could be intrinsically not consistent. The theory of the preference relationship systems states that the relationship of preferences and the relationship of indifference generated by a procedure of comparison between pairs of elements can be not transitive (e.g., a is preferred to b, b is preferred to c, but a can be not preferred to c).

If the matrix **A** is multiplied by the weight vector $\mathbf{w} = (w_1, w_2, \ldots, w_n)$, and given that the condition $a_{ij} = w_i/w_j$ must hold, one obtains:

$$\mathbf{A}\mathbf{w}=n\mathbf{w} \qquad \rightarrow \qquad (\boldsymbol{A}-n\mathbf{I})\mathbf{w}=0 \tag{1}$$

where **I** is the unit matrix.

This system has a not trivial solution if and only if the determinant of ($\boldsymbol{A}$-n**I**) is equal to zero, in other words, n is an eigenvalue of **A**. Furthermore, **A** has unitary rank given that each row is a constant multiplier of the first row and then all the eigenvalues, expect one of them, are equal to zero. The sum of the eigenvalues of a matrix is equal to its trace, that in this case is equal to n, so n is the maximum eigenvalue of **A** ($\lambda_{max}=n$) if the hypothesis of consistency is satisfied.

If the values of a reciprocal and positive matrix are slightly modified, the corresponding eigenvalues vary slightly in a continuous way. Then, it can be deduced that when the elements of the main diagonal of the matrix **A** are all equal to 1 and the matrix is consistent, if the values a_{ij} vary slightly the main eigenvalue of the matrix is not significantly different from n, while all the remaining eigenvalues are close to zero. Then, it can be reasonable to hypothesize that, in the general case, the weights are equal to the components of the main eigenvector **w** corresponding to the main eigenvalue λ_{max} of the matrix **A** [2]. Generally, a normalized solution, that is such that the sum of the values of the weight vector components is equal to 1, is preferred.

To verify the consistency of the matrix **A**, when the weights have been identified and the maximum eigenvalue is known, a consistency index can be computed as [1, 2]:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

If there is a perfect consistency, CI is equal to zero, while it increases if the consistency decreases. To measure the error due to the inconsistency, the value of CI computed for the examined test case can be compared with the value of the Random Index (RI) obtained as the average of more CI values coming from different reciprocal matrices of the same order, whose coefficients are generated in a pseudo-random way. If the value of CI for the examined case is larger than a prefixed threshold value (generally equal to 10% of RI), the deviation from the condition of perfect consistency is considered unacceptable.

3.4 The principle of the hierarchical composition

To define the importance of each element w.r.t. the goal, the principle of the hierarchical composition should be applied [2]. The local weights of each element are multiplied by those of the corresponding elements belonging to the upper level of the hierarchy and the obtained products are summed. Going from the upper to the lower level, the local weights of all the elements of the hierarchy are transformed in global weights step by step. The global weights (priority) of the elements at the lowest level of the hierarchy, located at the level immediately after that of the final objectives (the tree leaves) represent the main result of the evaluation process. If the final elements are actions, the values of the global weights identify a preference rank: an action (plan, projects, and so on) is as more preferable as greater is its global weight.

4 Application to a test case

The AHP method briefly described in the previous sections has been applied to evaluate the actions that should be considered to increase the customer satisfaction of the local public transit company (ATAM, Transit Company for the Metropolitan Area) that serves the city of Reggio Calabria, in the South of Italy. The transit system is characterized by bus service, medium frequencies, large served area.

The dominance hierarchy used in the work identifies at the upper level the user satisfaction (goal); the lower level includes 11 secondary objectives, that are the evaluation criteria fixed by the national directives (D.P.C.M., 30/12/1998, "General reference framework to draw up the transit service quality criteria"), that in turn have been used in the customer satisfaction interviews realized by the company. Particularly, the criteria identified by the national directives are: punctuality, regularity, comfort, crowding degree, cleaning, information system, accessibility, connections, environment, safety and security, courtesy.

The actions considered in this work are:

- fleet improvement: purchase of new buses to increase the overall fleet (10%) and replacement of the old buses (30%);
- staff investment: employment of new drivers (10%) and biennial staff formation and updating program;
- fleet improvement and staff investment: purchase of new buses to increase the overall fleet (5%) and replacement of the old buses (15%), plus employment of new drivers (5%) and yearly staff formation and updating program.

Note that all the identified actions should be considered at the same budget, in other words, for each action the same, prefixed maximum budget is available.

The dominance hierarchy used in this study is depicted in fig. 1.

All the criteria, except those referred to cleaning and courtesy, are involved in the first examined action (fleet investment), in fact the increase and the renewal of the fleet mean potential increase in punctuality and regularity (more buses, better service offered), comfort, accessibility and connections (more potential lines), information, environment, safety and security (new buses means technological equipments addressed to many aspects), as well as decrease in the crowding (more buses available to users for the same path).

The criteria involved in the second action (staff investment) refer to all the considered set except information and environment; in fact, the employment of new drivers can have the same effect of the fleet increase (but not in terms of advanced equipments addressed to user information and environment) and furthermore the formation and staff updating program makes the staff aware of the importance of the user satisfaction (specifically in terms of courtesy and cleaning).

Finally, the third action (fleet + staff investment) involves all the considered criteria.

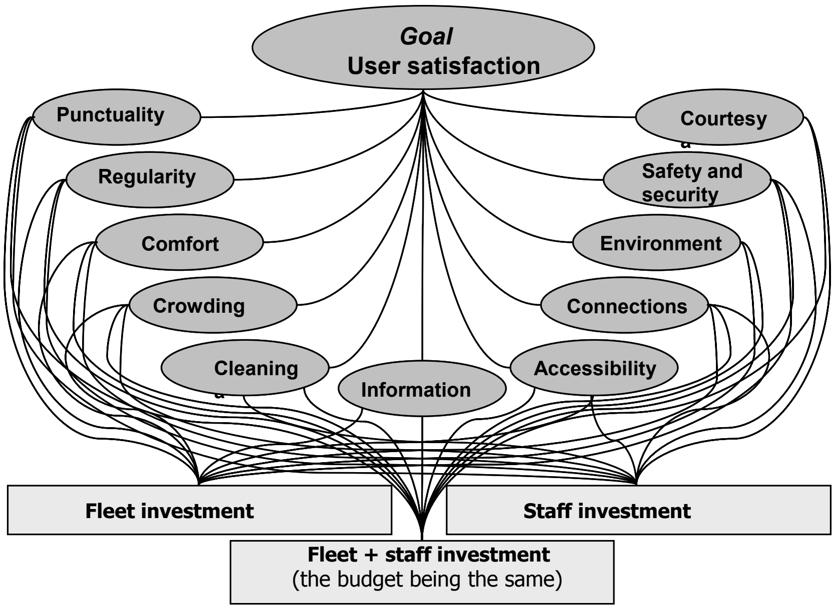

Figure 1: Dominance hierarchy for the test case.

To compute the comparison matrices the procedure already described in section 3 has been performed. Particularly, the matrix referred to the items linked to the goal (first level) has been computed by using the customer satisfaction interviews realized by the ATAM staff on board and at the bus stops in November 2004. The semantic scale has been used, because it is the more understandable and right for any interviewed user whichever his/her cultural level is. 500 useful interviews have been considered; the values used in the matrix are the mean values obtained over all the users, each of them has contributed to the computation of one matrix row (he/she provided 10 comparisons equal to about 18% of those that need to compute the overall matrix).

The local weights referred to the first level of the hierarchy, can be obtained by solving eqn. (1) directly or by using approximate methods:

the arithmetic average: $\hat{w}_{ij} = a_{ij}/(\Sigma_i a_{ij})$

$w_i = (\Sigma j \hat{w}_{ij})/n$

the geometric average: $w_i = (\Pi_j a_{ij})^{1/n}$

normalization

Fig. 2 depicts the results obtained by using eqn. (1) or the two approximate methods. As it can be seen the results are fully comparable and there are not significant differences in the results obtained. Note that the items in fig. 2 have been numbered as in table 1 that reports the synthetic values.

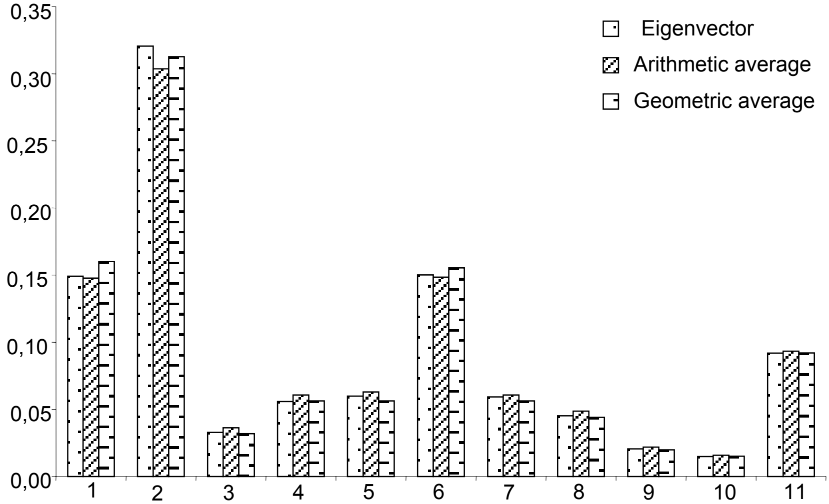

Figure 2: Local weights computation: comparison with different methods.

Table 1: Local weights of the items associated to the goal.

		W	$W_{normalized}$
1	Punctuality	0,89	0,15
2	Regularity	1,90	0,32
3	Comfort	0,19	0,03
4	Crowding	0,33	0,06
5	Cleaning	0,35	0,06
6	Safety and Security	0,89	0,15
7	Information	0,35	0,06
8	Accessibility	0,27	0,05
9	Courtesy	0,19	0,02
10	Environment	0,09	0,01
11	Connections	0,55	0,09

In terms of specific results, the examination of the local weights for the items directly linked to the goal (table 1) shows that regularity is the most important aspect considered by users, followed by punctuality, safety and security.

The consistency index is about 10% of the random index (*CI*=0,16; *RI*=1,56) and then the estimates of the weights can be considered reliable.

The estimation of the global weights for the three actions, that should be considered as priority for the company, produces the following results: fleet investment: 21,7%; staff investment: 28,3%; fleet + staff investment: 50,0%, thus the preferred action is the last one.

5 Conclusions

The AHP method described here has been tested on a real case, in order do verify its applicability and the reliability of the input data obtained within the customer satisfaction survey. From a general point of view, the AHP method can be used to evaluate the priority of possible actions when the involved factors can be determined in a qualitative rather than quantitative way. Among the advantages of the method there is the opportunity to use simple question to rank preferences; furthermore, the method does not require the perfect consistency to be applied. Among the disadvantages, there are the arbitrary choice of the semantic scale and the potentially high number of the pair-wise comparisons that increase the probability to obtain inconsistent matrices. Moreover, the method presents the problem of the rank reversal, i.e. the final ranking obtained by means of the weights depends on the alternatives present when the analysis starts. In other words, if a new alternative is added the final ranking can lead to a reverse order for alternatives already examined. Analyses with multi-level hierarchy are more suffering from rank reversal problems, but it can be overcome by means of suitable techniques [7, 8].

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