THE AHP APPROACH FOR RAILWAY PROJECT APPRAISAL: PROPOSAL FOR A SPECIFIC PROBLEM STRUCTURE

Giovanni Longo
Giorgio Medeossi
Stefano Strami
Department of Civil Engineering and Architecture
University of Trieste, Italy
E-mail: longo@dica.units.it, giorgio.medeossi@phd.units.it, stefano.strami@phd.units.it

Elio Padoano[*]
Department of Mechanical Engineering and Naval Architecture
University of Trieste, Italy
E-mail: padoano@units.it

ABSTRACT

The paper offers a new railway-specific decision structure that may be used in the field of railways. The aim is to support decision makers with a set of specific indicators that offer a technical description of the considered infrastructural alternatives in terms of capacity, regularity and other aspects. Such criteria may be considered in decision problems in this field, together with those related to economic, financial and environmental factors.

Keywords: AHP, multi-criteria, railway, transport, infrastructure, simulation

1. Introduction

The problem of choosing among a set of candidate infrastructural projects in the transportation field generally implies a wide variety of decision criteria (ranging from capacity matters to ticketing revenues and water contamination), and involves many political actors and stakeholders. Therefore, this has been a very fertile field for the application of multiple-criteria decision-making methods in recent years (see for example, Barić et al., 2006; Zietsman, 2006; Tsamboulas, 2007; Mateus et al., 2008).

The study intends to propose a new way of structuring the problem of choosing the most preferable infrastructural alternative, which allows to take into account not only the drawbacks of every possible option, but also the positive effects of each project. Most of the applications in this field, in fact, offer an in-depth analysis of the negative impacts of all the possible decisions (these being generally emphasised by local authorities or pressure groups), without detailing thoroughly the reasons for the actual realization of the project. It is evident that, when a new alternative is proposed during a decision-making process, a positive effect is foreseen; nevertheless aspects such as costs and environmental impact are often the most accurately measured. Nonetheless, topics like possible economic revenues, positive effects on the social sphere or specific transportation-related matters are left on the background.

This paper presents a model that includes quantitative and qualitative criteria such as, for instance, the flexibility rate of the rail infrastructure, the comfort offered to travellers, access times to stations, vehicle maintenance savings, served population, ticketing revenues and so forth. The objective of this paper, therefore, is to introduce a new structure for the decision problem that includes criteria related to the positive outcomes of each possible alternative, in juxtaposition to their well-known negative effects. Furthermore, most of such positive outcomes are measurable directly or they can be assessed by means of descriptive or simulation models, whereas the remaining ones can be evaluated via judgements by experts.

---

[*] corresponding author

Some of the transport-related criteria, in fact, are related to the inputs and outputs of stochastic simulations, which represent a fundamental support tool in the development of infrastructural projects.

The aim is to support a decision by means of a technical and rational base that, in our opinion, is particularly effective, when illustrating pros and cons of the candidate solutions to a panel of consultants as well as to local authorities and the public opinion. Decisions concerning infrastructural projects are frequently submitted to a discussion process in which several stakeholders participate directly or by means of nominated experts (actors of the process – see e.g. Banville et al., 1998). It is not rare that actors' judgments diverge: in such cases the most robust opinions are those that come from the more legitimated participants (because of their role or expertise) or those that are based on the most solid argumentation (Saaty, 2008). Problems can occur more frequently when priorities have to be assessed to objects (criteria or candidate solutions) that do not have a clear definition or that can be perceived in very different ways (a typical example is the criterion "aesthetics"). An effective definition of performance measures is particularly important in the field of transport infrastructure for the conceptual construction of a solid argumentation. In this context, technical data or functional models are not meant to replace a confrontation on an object priority, but they constitute a fundamental support tool to make sound decisions.

2. The proposed structure

The decision problem is structured as a hierarchy (Fig. 1). At the first level the criteria are grouped into four categories: "Economic and Financial", "Transport-related", "Social" and "Environmental". Some of these sets are further developed in subcategories, grouping subcriteria into more specific clusters.

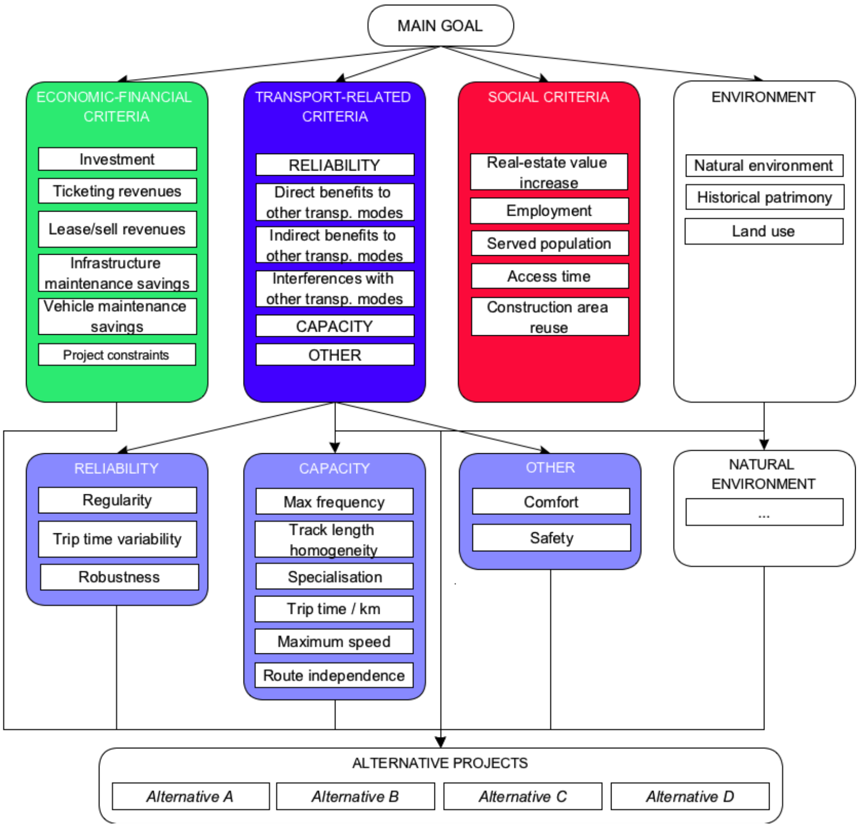

Fig. 1 – The specific AHP structure proposed for railway infrastructure choice problems

Two of the considered categories are those typically included in the majority of studies, as far as transportation infrastructures are concerned – Economic and Financial criteria and Environmental Impact indicators. With reference to the first set, along with criteria like "*capital investment*" the model suggests to calculate the different "*ticketing revenues*" related to each alternative project (which depend on the served traffic demand in each situation), as well as revenues obtained through the "*lease or sell"* of station facilities and the "*savings"* in terms of infrastructure and rolling stock "*maintenance"*, resulting from different project solutions. Considering the Environmental impact indicators, the existing literature (see, for instance, Pak, Tsuji and Suzuki, 1987) already specifies all possible outcomes to be included in the analysis, from negative effects on the "*natural environment*" to damages to the "*historical patrimony*" and "*land use*". The evaluation of all of these aspects can be deepened as required by the specific decision problem, usually structuring the problem situation in a number of hierarchically dependent subclusters.

When facing a decision problem regarding the choice among different railway infrastructure projects, social aspects are also significant and may favour one alternative instead of another. Among these, the "*served population"*, the "*employment*" related to the building site, the "*real estate value increase*" for those regions linked by the new line, "*access times*" necessary to reach a station from a specific point of interest and the possible "*reuse"* of the construction area for other purposes (gardens, parking lots etc.) can be cited.

In addition to these criteria, which belong to categories that are often included in such analyses, the new decision structure proposes a whole set of technical transport-related criteria which are detailed in the next paragraph. Several of these criteria are associated to parameters or indicators that can be directly measured, or that can be assessed by means of analytical models applied to transportation networks.

3. Transport-related criteria

Among the criteria that are specific of railway decisions (either concerning station layouts or line projects), the proposed AHP structure includes:

1. *Direct benefits* to other transportation modes;
2. *Indirect benefits* to other transportation modes;
3. *Interferences* with other transportation modes;
4. Reliability indicators: *Regularity*, *Trip time variability*, *Robustness*;
5. Capacity indicators: *Maximum departure frequency*, *Track length homogeneity*, *Specialisation*, *Route independence*, *Trip time* per kilometre, *Maximum speed*;
6. Other criteria: *Comfort, Safety*.

Direct benefits are those deriving from the solution of existing conflicts among infrastructures – such as at-level crossings between railway lines and roads – which results in a higher capacity on both sides. *Indirect* ones, instead, are related to the modal shift of part of the mobility demand from the surrounding roads to a new railway line or station. Such new facilities may thus make the existing road less congested, therefore more appealing. Together with benefits, also new *interferences* among transport modes may arise from the realisation of a new infrastructure, which may influence, for instance, the way the traffic flows in the surrounding areas.

The rate of reliability of railway networks is a crucial aspect in the choice among alternative projects and can be quantified through three criteria closely related to railway simulation outputs: *regularity*, as the average delay in perturbed conditions; *trip-time variability*, i.e. its standard deviation obtained by simulation and *robustness*, a measure of the reliability of a network (e.g. a station yard layout) that will be further described in the next paragraph.

Another fundamental characteristic to be taken into account in this kind of decision problems is capacity, both for station yard layouts and for railway lines. Capacity can not be measured as such - it is more precisely the result of a mix of criteria closely interconnected with each other. The whole set of indicators can provide an idea of the right compromise between the number of trains running per time unit and the degree of regularity of circulation, which in turn influences the complexity of operations. Therefore, this aspect can be treated in a specific subcluster containing a number of nodes, depending on the specific case study: *maximum departure frequency* (in trains/h), *trip time per kilometre* and *maximum speed* (km/h) are self-evident concepts. In addition to these, one may include the *rail track length homogeneity* within a station, in terms of number of module-long tracks over the total number (the 'module' being the maximum length of trains that can circulate on a line, which depends on the track length in crossing station yards). Other criteria, that are related to infrastructure capacity are the *specialization rate* of a station layout, an indicator of the possibility of separating the different train services (commuter, long-range and freight for example – a higher of separation results in a higher capacity, as slow trains do not influence the flow of the fast ones) and *independence rate* among itineraries within a station. The last aspect is specified better in the next paragraph.

Finally, among the transport-related criteria cluster are other nodes like *safety* and *comfort*, which could be quantified via pairwise comparison, using the fundamental scale of the AHP.

In the following paragraphs (§3.2 and §3.3), two of the proposed criteria are described, with particular reference to how they can be quantified with the aid of stochastic simulation. A brief introduction to railway micro-simulation is presented in paragraph 3.1.

3.1 Introduction to railway micro-simulation

Stochastic micro-simulators can reproduce most processes involved in rail traffic and comprehend not only its deterministic aspects, but also human factors. This is particularly relevant in order to simulate traffic under realistic conditions, considering variability at border, various driving styles and stop times. Starting from a precise infrastructure model, a planned timetable and the rolling stock characteristics, micro-simulators use a mixed discrete/continuous simulation process that calculates both the continuous numerical solution of the differential motion equations for the vehicles (trains), and the discrete processes of signal box states (Fig. 2). If calibrated random distributions of the most common process times (departures, stop times and train performances) are also inserted, micro-simulation offers also a very realistic representation of train traffic (de Fabris, Longo and Medeossi, 2011). Therefore, stochastic simulation can be used to obtain a number of parameters strictly related to the behaviour of the system, such as punctuality ("*regularity*"), "*trip time variability*", and even "*capacity*" indicators, especially when the trade off between capacity and reliability is considered. Stochastic micro-simulation has been widely used for ex-ante reliability estimations, performed on timetable drafts in complex railway nodes, such as Rome, Milan, Naples, Turin, Florence and Venice.

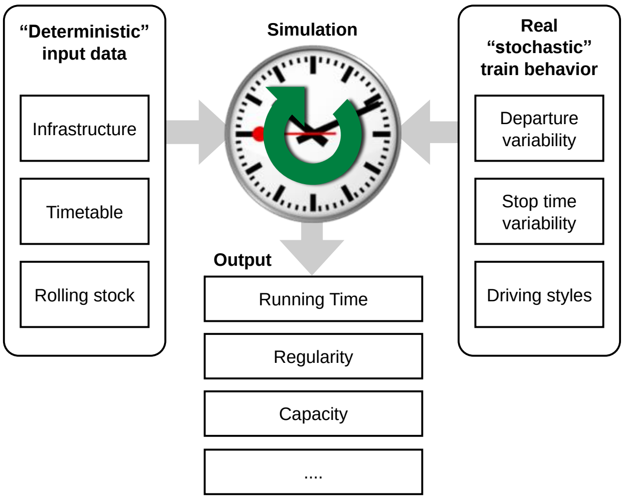

Figure 2 – Input and output of railway micro-simulation

3.2 Itinerary independence

Thanks to the integration of a simulation software product and worksheets macro programming, the calculation of some capacity indicators was automated and tested on a complex railway node. In particular, starting from the station layout elements that constitute part of the simulation input, the script is able to calculate all possible n-uples of independent itineraries that can be run through at the same time. Each itinerary within a station is described as a sequence of nodes in the simulation software. Each of these sequences is compared to all others, thus highlighting the existing conflicts. The second step is to compare each couple of the previously calculated independent itineraries with the remaining itineraries, so as to determine a set of independent triples. The process is then iterated *n* times by comparing all n-uples of independent itineraries with all other routes, until no (n+1)-uple of independent itineraries can be found.

Joining the independence information and the train service timetable, a common itinerary independence index is also obtained – the *weighted route locking rate*. The timetable is fundamental to weigh each itinerary with the number of trains that are planned to run through it. When comparing two alternative infrastructure projects, a lower locking rate would be preferable, as it indicates the possibility of shunting a higher number of trains per time unit.

This approach has been successfully applied to a complex Italian railway node, Verona Porta Nuova, obtaining a maximum number of 6 contemporary train movements. The degree of independence among itineraries brings a lower risk of conflicts among trains running through a station and therefore provides a higher capacity in terms of possible services per time unit.

3.3 Robustness

The concept of robustness of a transportation network extends the traditional definition of efficiency of a complex network, which has been defined as the ability in communicating and in exchanging information between nodes to a new measure of efficiency for time-related systems. Complex network theories are able to find critical paths and routes in a common railway station. This is made by physical elements (tracks, switches) and service constraints (routes, signals). When a failure occurs in one part of the station layout the reaction of the system has to be evaluated in function of the amount of trains that are planned to run through the critical element.

This criterion can be quantified with an indicator called “Information Centrality”. This concept is very useful in network analysis because it takes into account the relative importance of a node (or of any other element) within the graph (i.e. the station network layout). The indicator makes use of Dijkstra’s shortest path algorithm to quantify the relative increase in the length of all itineraries when a node is not available in the network (when, for example, an accident occurs or a switch is out of order). A set of alternative infrastructural projects can differ appreciably with respect to this aspect and when comparing some possible improvements to an existing station this indicator is highly useful. Its validity was tested on a real case – the large-sized railway node of Padova in Italy – where stochastic simulations confirmed the ranking in the “degree of importance” of station yard nodes obtained with the Information Centrality indicator (Lamanna, Longo and Medeossi, 2011).

4. Conclusions

The proposed multiple-criteria decision structure aims at satisfying the lack of quantitative information noticed in a number of project evaluations in the field of railway infrastructures. The intention is not to belittle the importance of utility judgements, but the authors’ opinion is that this way of structuring the problem may aid decision makers in deeply understanding the significance of each analysed project. Thus, decision makers could then evaluate the performance of the alternatives according to their judgement scales, relying on a solid technical basis. The proposed criteria were obtained in a number of major Italian railway nodes proving to be based on robust and reliable methodologies.

Among the possible future developments, the presented model could be further enhanced by analysing more deeply the role of each actor in the decision stages and by specifying all possible interrelationships among actors and criteria through an ANP (network) structure. Criteria may also be arranged in a flexible BOCR, by evaluating Benefits, Costs, Opportunities and Risks associated to each alternative separately.

REFERENCES

Banville, C, Landry, M., Martel, J.-M. & Boulaire, C. (1998). A stakeholder approach to MCDA. *Systems Research and Behavioral Science, 15(1),*15-32.

Barić, D., Radačić, Z. & Čurepić, D. (2006). Implementation of Multi-criteria Decision-Making method in selecting the railway line for reconstruction. *10th International Conference on Transport Science*. Portoroz.

de Fabris, S., Longo, G. & Medeossi, G. (2011). An implementation of stochastic blocking times to support timetable planning. *Proceedings of the 4th International Seminar on Railway Operations Modelling and Analysis*. Rome.

Lamanna, F., Longo, G. & Medeossi, G. (2011). Robustness and Protection Strategies of Station Tracks Layout. A New Approach Based on Complex Networks Theories. *Proceedings of the 4th International Seminar on Railway Operations Modelling and Analysis*. Rome.

Mateus, R., Ferreira, J.A. & Carreira, J. (2008). Multicriteria decision analysis (MCDA): Central Porto high-speed railway station. *European Journal of Operational Research, 187*, 1-18.

Pak, P. S., Tsuji, K. & Suzuki, Y. (1987). Comprehensive evaluation of new urban transportation systems by AHP. *International Journal of Systems Science, 18(6),* 1179-1190.

Saaty, T. L., (2008). Relative Measurement and its Generalization in Decision Making. Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors. *The Analytic Hierarchy/Network Process, 102(2)*, 251-318. RACSAM.

Tsamboulas, D. (2007). A tool for prioritizing multinational transport infrastructure investments. *Transport Policy 14,* 11-26.

Zietsman, J., Rilett, L. & Kim, S.-J. (2006). Transportation corridor decision-making with multi-attribute utility theory. *International Journal of Management and Decision Making, 7(2/3).*