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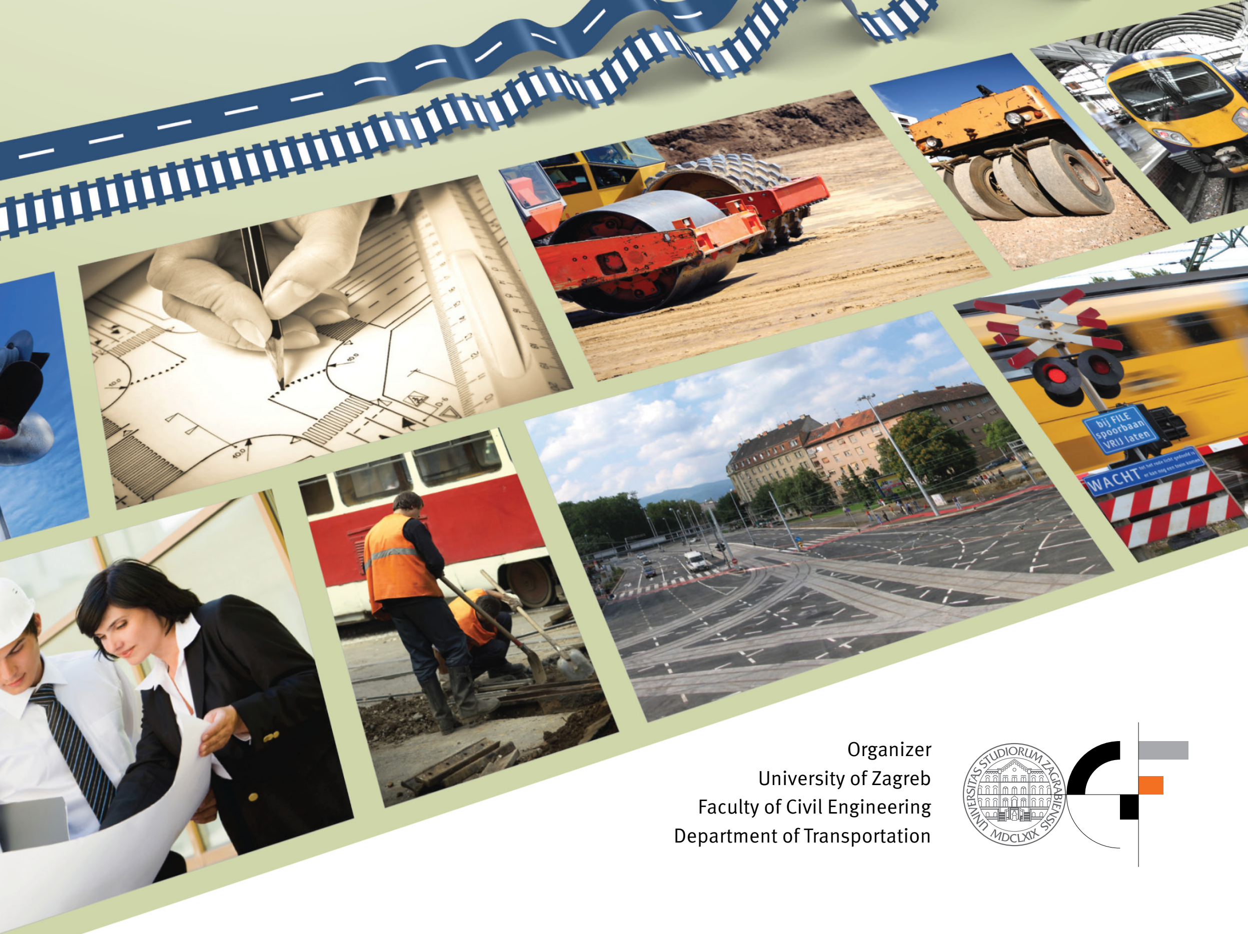
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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USING SIMULATION TO ASSESS INFRASTRUCTURE PERFORMANCE IN MULTICRITERIA EVALUATION OF RAILWAY PROJECTS

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Abstract

Economic evaluation of projects of new railway infrastructures is a typical step of feasibility studies, but it is rather common to take into account other than transport aspects of projects such as their environmental or land use outcomes. Multicriteria methodologies may support decision makers during the process of evaluation and choice of candidate projects; notwithstanding a large part of the applications in the railway sector carry out a careful analysis of the negative impacts of the alternatives, but the reasons for the actual realization of the project are neglected. In fact, a railway infrastructure project aims to improve an existing situation by means of expected positive effects on, for example, accessibility or travel times. Nonetheless, the economic revenues, the positive effects on the social sphere or the specific transportation–related matters that a project might generate are often left in the background. The authors propose a model that includes different attributes that can characterize a railway infrastructure, e.g. the flexibility rate, the comfort offered to travellers, the access times to stations, the vehicle maintenance savings, the served population, the ticketing revenues. Thus the aim of this paper is to introduce a new structure for the decision problem that includes criteria related to the positive outcomes of each alternative project as well as its negative effects. It is worth noting that positive outcomes are, to a great extent, measurable directly or they can be assessed by means of simulation models. Some of the transport–related criteria are indeed related to the inputs and outputs of stochastic simulation, which can reproduce most processes involved in rail traffic, including deterministic aspects and human factors. This is particularly relevant in order to simulate traffic under realistic conditions, considering variability at border, various driving styles and stop times..

Keywords: multicriteria evaluation, AHP, railway traffic simulation

1 Introduction

A project for a new railway infrastructure requires a series of activities that involve several competences. Among these, the assessment of different possible solutions is of paramount importance as it makes it possible to identify an effective solution. The problem of choosing among a set of candidate infrastructural projects generally implies a wide variety of decision criteria and involves many stakeholders. Therefore, the application of multi–criteria decision–making methods has been quite common in recent years (see for example, [1] [2] [3]).
This paper 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. The main objective is to introduce a new structure for the decision problem that includes criteria related to the positive outcomes of each possible alternative, in concurrence 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. 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 railway projects.

2 The problem of choice in railway projects

Transportation infrastructural projects involve large amounts of resources and have effects on several aspects relating to the social sphere and to the environment. It is then clear that they drive the attention of subjects, organisations and communities that could be affected. In general, these kinds of projects are starting to solve mobility problems or to take up funding opportunities. It is rather common to carry out a feasibility study in which different solutions are identified and characterised at a sufficient level of technical detail. Often the solutions are structured in the form of 'alternatives' which form a set of mutually exclusive elements; this poses a problem of choosing the one that is the most effective for achieving the objectives of the project. Therefore, this part of the project requires analysis, evaluation and decision with respect to the set of the technically feasible alternatives.
In order to take into account different points of view that may be interested by the project implementation, the alternatives 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. [4]). The role of the experts is to examine in detail the characteristics of the alternatives from different perspectives of analysis and evaluation (technical, economic, social, environmental etc.), supporting the reasons of the dimension pertinent to their expertise and the arguments of the stakeholders who they represent. Actors' judgments might 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). A proper analysis and assessment of the solutions can be assured by considering two aspects:

- structuring a framework to support the examination;
- identification of the criteria for the evaluation that are pertinent to the decision.

The analysis and evaluation requires, on one hand, that the peculiar attributes of the alternatives should be put into evidence and, on the other hand, that the criteria for evaluation should be clearly stated. A framework that helps to perform practically this task is therefore advisable. Several authors (e.g. [6] [7]) have observed that a hierarchical structure is particularly effective: from the main objective (or goal) of the decision problem it makes it possible to detail progressively the evaluation criteria up to a level that can be used to assess the alternatives. This kind of structure is employed in the Analytic Hierarchy Process (AHP) multi–criteria method.
The identification of the criteria should take into account different stakeholders' objectives and the main goal of the project. Most of the applications concerning transportation infrastructures frequently offer an in–depth analysis of the 'negative' attributes related to the candidate solutions (impacts), without detailing thoroughly the positive outcomes attributable to the project. It is evident that when a new infrastructure is proposed, a positive effect is foreseen; nevertheless aspects such as capital 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 in the background. Figure 1 shows a hierarchy that includes the main dimensions of evaluation that are traditionally taken into consideration in multi–criteria decisions concerning railway infrastructures.

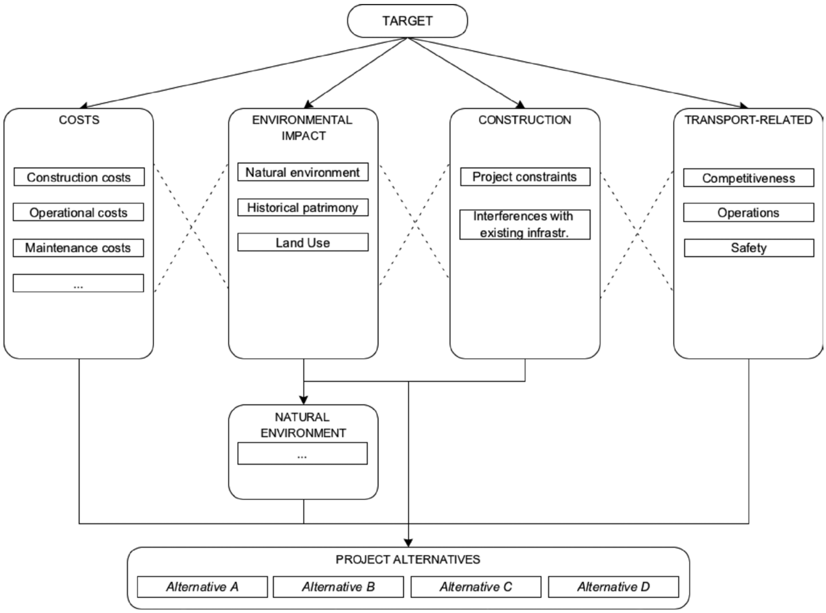

Figure 1 A hierarchy of criteria to assess railway infrastructures

Such problematic issues can occur more frequently when priorities have to be assessed to objects (criteria or candidate solutions) that have a 'rough' 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 to build a solid argumentation. It must be underlined, though, that technical data or functional models are not meant to replace a confrontation on a subject of the decision process, but they constitute a fundamental support tool to make sound decisions.

3 The proposed model

The proposed model includes criteria pertinent to different dimensions of evaluation and takes into consideration attributes that are commonly considered as positive effects or as negative outcomes of an infrastructural project [8]. The decision problem is structured as a hierarchy (Figure 2). At the first level the criteria are grouped into four categories: 'Economic and Financial', 'Transport–related', 'Social' and 'Environmental'. Some of these dimensions are further developed in subcategories, grouping subcriteria into more detailed and specific clusters.

Two dimensions are commonly included in many studies related to transportation infrastructures: Economic and Financial criteria and Environmental Impact indicators. With reference to the first one, along with criteria like 'capital investment' the model proposes to take account of the different 'ticketing revenues' related to each alternative solution, which depend on the served traffic demand in each situation, as well as of revenues obtained through the 'lease or sell' of station facilities and the 'savings' in terms of infrastructure and rolling stock 'maintenance'. So far as the Environmental impact indicators are concerned, several authors (e.g. Pak, Tsuji and Suzuki, 1987) already specify all possible outcomes to be included in the analysis: impacts on the 'natural environment', damage to the 'historical patrimony', effects on 'land use'. The evaluation of all of these aspects can be further detailed 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 alternative railway infrastructures, social aspects are also significant and may favour one alternative instead of another. These include the 'served population', the 'employment' related to the building site, the 'real estate value increase' for those regions linked by the new line, the '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.).
To integrate these criteria, the new decision structure proposes a set of performance measures that characterise solutions from a technical point of view; the set is 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 or simulation models applied to transportation networks.

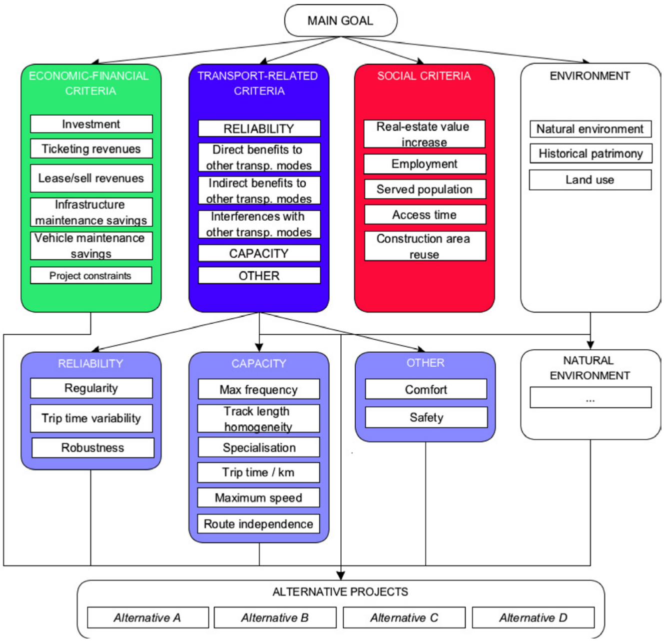

Figure 2 The hierarchy of the proposed model

4 The transport–related criteria

As shown in Figure 2, the model identifies several criteria that are specific of railway decisions (either concerning station layouts or line projects). Direct benefits can derive from the solution of existing conflicts among infrastructures – such as at–level crossings between railway lines and roads – which results in a rise of capacity at system level. 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. Besides, 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, which may be measured in different ways such as for example the average delay in perturbed conditions; trip–time variability, i.e. its standard deviation obtained by

stochastic micro–simulation (described in the next paragraph) and robustness, a measure of the reliability of a network (e.g. a station yard layout) (see [12]).
Another fundamental characteristic is capacity, both for station yard layouts and for railway lines. Capacity, 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.

4.1 Simulation

Stochastic micro simulation can model train operations and reproduce most processes involved in rail traffic. It comprehends not only its deterministic aspects, but also human factors thus considering the real behaviour of trains and representing signalling, ATC systems, and other technical parameters. Simplified dispatching is also provided by local conflict resolution, and stochastic train behaviour can be inserted using multiple simulations. 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 (figure 3). It may be used to estimate the system behaviour in different scenarios.

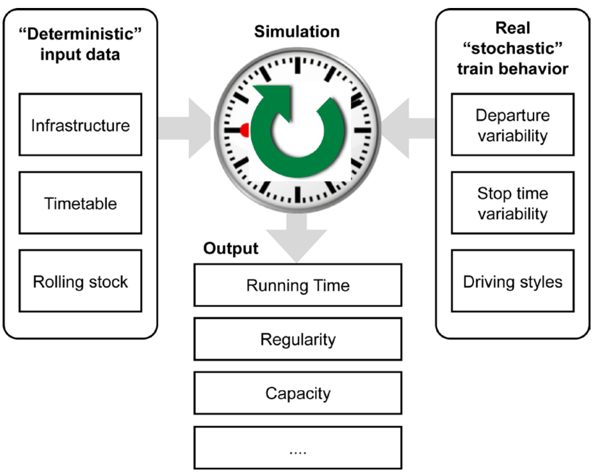

Figure 3 Input and output of railway micro–simulation

Stochastic micro–simulation can be seen as a very precise way to model train operations on a network, obtaining knock–on delay and punctuality estimations and allowing users to evaluate various rolling stock, infrastructure layouts and timetable.
It 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. These aspects are usually very important in new railway projects assessment as the increase of capacity (to serve increasing demand flows) and the improvement of traffic reliability are main goals in many countries.

4.2 Itinerary independence

Thanks to the integration of the micro–simulation model and worksheets macro programming, the calculation of some capacity indicators may be automated and it has been 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 model. 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 weight 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 complex Italian railway nodes. 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.

5 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. This lack in particular refers to the estimation of positive performances of the alternatives, while usually their negative externalities are well known and quantified. 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. They allow the measurement of some aspects, whose importance in railway projects assessment is really high.
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.

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