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Railway Capacity Handbook: A Systematic Approach to Methodologies

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Abstract

Additional demand to be placed upon railways in Europe in order to provide third party usage of infrastructure is the today's basic theme of railway capacity. The complete separation of railway infrastructure ownership and operation is also a potential reality in the near future, which would result in even greater competition for railway infrastructure. Furthermore, when capacity analysis is requested, the choice between available procedures is not easy. Difficulties include the numerous interacting/interrelated factors, the complex structure of the railway layout and the magnitude of terminology required. The present paper focuses on the available and/or common used techniques and methodologies for valuating railway capacity. In the paper, a new proposal of coordinate use and comparison of methods to perform capacity analysis is presented.

Keywords: Track capacity; Capacity of nodes; Railway capacity calculation methods

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1. An overview of the research

The present research, presents the third and last part of the ongoing Ph.D. research which has been started on November 2008, concerning capacity analysis techniques and methodologies for railway systems management. The global aim of the research is to offer a technical manual including of overview and descriptions of common consolidated analysis which performs the evaluation of railway capacity. The term Railway capacity however is an elusive concept difficult to be defined or quantified. For that reason the research has been divided into three main categories of analysis.

1.1. The first Part

A first part of this research was presented in the 3rd International Seminar on Railway Operations Modeling and Analysis (RailZurich2009) in which the following main tasks have been illustrated:

- Definition and illustration of main introductive concepts to perform capacity analysis;
- An accurate description of the available methods for railway lines capacity classified by sector of interest, with a particular attention to point out all factors having a direct relation to the obtained results (Input / output comparison analysis);
- A first comparative analysis of functionalities of techniques for railway capacity calculation which has illustrated the ability of the methods to deal with the typical operational situations and standards.
- The correlation between the simulation environments developed by researchers and the data normally managed by infrastructure managers and railway operators;
- An elementary comparative analysis of functionalities of simulation methods and environments for railway traffic simulation.

1.2. The second part

The second part of this research was presented in the 4th International Seminar on Railway Operations Modeling and Analysis (RailRome2011) in which the following main tasks have been illustrated:

- Accurate description of the available methods for railway capacity of nodes classified by sector of interest, with a particular attention to point out all factors having a direct relation to the obtained results (Input / output comparison analysis);
- A comparative application of functionalities of techniques for railway calculation on a portion of the Italian railway network. The selected branch, with an overall length of 92.2 kilometers, has 11 stations including the rail head and 9 intermediate stops. The critical section has a total length of 13.2 kilometers and two intermediate stops.

1.3. The third and last part

While railway operation simulation is now a proven analysis tool and increasingly used worldwide, many models, by some standards, are still relatively primitive. The most popular simulation models have their roots in addressing very specific problems. Some models are impressive in their appearance, but weak in their logic and performance. Others apply more rigorous logic but are hard to use. The revealed

current trend is to develop integrating tools covering a phase of capacity management: analytical for the preliminary solution, optimization for timetable generation and simulation for timetable validation. Therefore functional clustering and aggregation of methods in macro categories is a result of this phase and the premise to build up new integrated methodological approaches to be validated. The research provides a comprehensive database consisting of papers studying railway capacity calculation that were published in scholarly journals (international publishers) since 1950: a total of forty-eight methods and forty simulation tools have been studied. Whenever possible, the authors were also contacted to deepen the knowledge or request more clarification.

Once the above described analysis has been completed, the obtained results permitted the implementation of the original assessment tool, named RC-k, which is running in pilot version on the web (under www.rc-k.info). It is free of use and aims to attract the interest of both academicals institutions and/or technical-scientific as well as operational interested subjects.

The RC-k tool purposes are:

- to disseminate the activities and research output by providing open access to the research and analysis;
- to establish and foster a knowledge exchange network of scholars, policy-makers, practitioners and students interested in railway capacity;
- to generate a user-friendly interface system which allows interaction and comparison between all railway actors;
- to form a technical handbook of theories on which capacity calculation methodologies and techniques have been based on;
- to provide a comparative analysis of available calculation methods (lines and/or nodes) based on the selection of user's scope input data.

2. The RC-k tool's architecture

The RC-k tool's architecture has been thought as user-friendly interface system offering an easy introduction modality of input data and allowing railway actors to obtain a comparative analysis of different methods of calculation along with some useful bibliographic data. The main goal of the authors is to offer a new system, which can be complete as for the technical part and can also function as a interface of communication and comparison. In fact the architecture, which the tool is based on, has been simplified as much as possible in order to provide an easy access data mode and in the same time permit to the user to "undo" his choices in any step of the application. In fig.1 a block diagram is presenting the RC-k tool's architecture.

2.1. Adopted assumptions

The present work refers to the number of traffic units, i.e. the number of trains running during the reference time. In order to express the value of capacity in terms of the number of people / objects transported during the reference time, the concept of a nominal capacity of the transport system, also called Transport Capacity, was introduced. This term may be referred to the components of the railway system: lines and nodes.

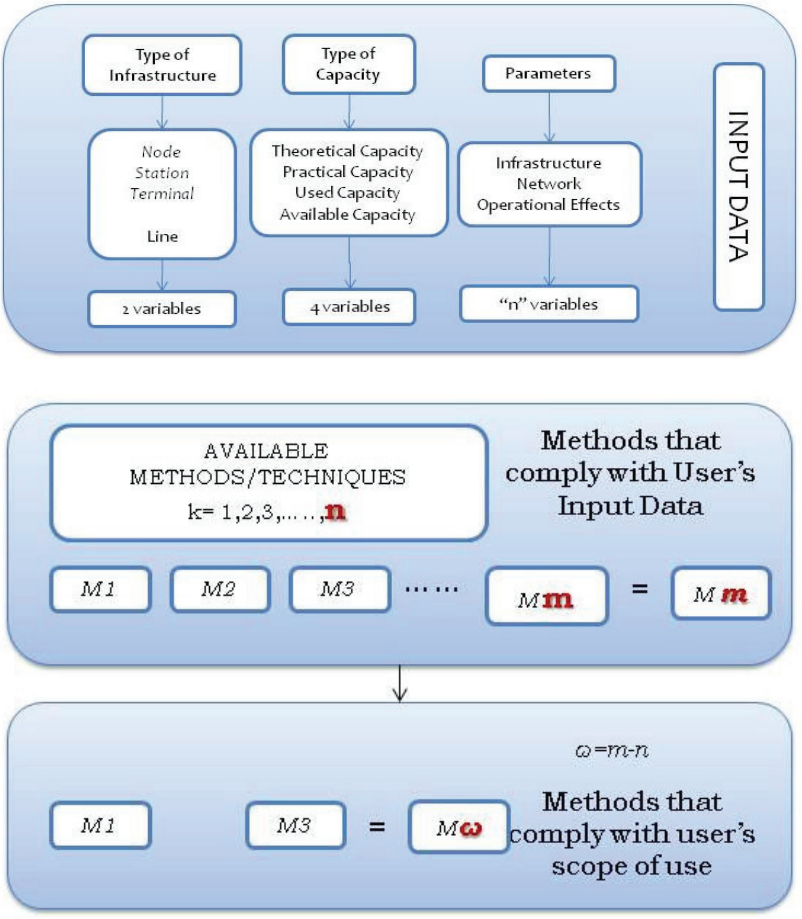

Fig. 1 Schematic representation of RC-k architecture.

The RC-k architecture is based on the schematic representation of Fig.1. The introduction of user's input data leads to a first screening of the methods that comply with them for a total of "n" methods. The user can also perform another filter by choosing some of the above "n" methods, for a total of "w" methods. Consequently the application window is activated as it will be described in the following paragraph.

3. The RC-k application

3.1. Input Data

The first step to follow is the definition of the iput data. The user must first decide whether the calculation of railway capacity regards a railway line or node. In the rail traffic technique, the capacity of lines and nodes is a key issue, since it summarizes in numerical values, the set of functional

characteristics of lines and stations themselves, combined with those of vehicles running on them. Given the heterogeneous multitude of factors that affect that capability, a unique definition is not possible.

3.1.1. Line Capacity

The capacity of a line is defined as the number of scheduled trains that can run on the line in the reference time.

Key elements that have a direct influence on the value of the capacity are:

- geometrical configuration of the track;
- line and stations and lay-out;
- features of signaling systems;
- movement rules and corresponding minimum distance between trains;
- Operation and maintenance planning.

3.1.2. Capacity of Nodes

The capacity of a node must be considered as the capability of the node itself to receive trains on the tracks in the reference time without delays at traffic signals.

It depends on the structure of the timetable or rather by the frequency of arrivals, which regulate the minimum lines headway, the topology of the system which determines the incompatibility and the interlocking system features.

The second step is the definition of the requested type of railway capacity that the user wants to obtain. Four types of railway capacity have been taken into account. The Theoretical Capacity is defined as the number of trains that could run on a certain line section in a defined reference time in case of unperturbed operation, corresponding to the headway for all classes of trains and operational programmes. The Commercial Capacity represents the portion of the actual capacity calculated taking into account the actual operation of the railway and its interaction with the network. The Used Capacity is the actual capacity committed by a particular rail system under certain operating conditions that is absorbed by a timetable. The Residual Capacity is the portion of the capacity still available to meet new demands in a timetable and/or under perturbed operation.

At the third step, the user should list the available input data and select the relative fields into the three main categories defined as: Infrastructure Parameters, Network effects and Operational effects. This categorization is due to the fact that railway capacity is not static. It is extremely dependent on how it is used. The physical and dynamic variability of train characteristics makes capacity dependent on the particular mix of trains and the order in which they run on the line. Furthermore, it varies with changes in infrastructure and operating conditions. Also the above three categories defined give a first element on the way different factors that affect on railway capacity are linked.

The steps above complete the user's input data procedure. The system takes into account these data, elaborates the different combination of the above and generates a first list of available methods of calculation of railway capacity. Available methods are those that have been analyzed by the authors during the present research and comply with user's selection of input data. The different techniques and methodologies for calculating the capacity can be divided into three main categories according to the used methodology, the compiled data and the level of detail. They are:

- Synthetic: they use deterministic expressions, i.e. the variables contained in these cannot change its state and assume fixed values during the reference time; from the mathematical point of view they are equations were the unknown quantities are mutually independent, they are also called Static;
- Analytical: they use probabilistic expressions; from the mathematical point of view they are equations were the unknown quantities are mutually dependent, they are also called Dynamic;

- Analogical: can be further divided into asynchronous methods (this covers methods which provide the optimization of one or more variables) and synchronous methods (traffic simulation), for instance the optimization methods are based on procedures looking for delays minimization in the mixed speed traffic, as well as the simulation methods represent the evolution of advanced research and are often used to validate the results of other methods.

The present research uses bibliographic tools to provide further quantitative and qualitative information on railway capacity. The bibliographic analysis aims to address the following issues:

- which are the characteristics of the railway research (i.e. research approach)?
- can groups within the research community that focus on particular type of railway capacity be identified?

The system provides a chronological identification of each available method and gives the possibility to the user to confirm his interest by selecting the confirmation field. In Europe the development of methods and/or simulation tools is large, not only in academic frameworks but also in companies managing railway infrastructures and traffic and also in those marketing the need for tools capable to provide with answers to their multiple needs. It is therefore useful to provide references to this evolution in time and worldwide.

In this stage the user selects the group of methods that are going to be elaborated by the system and will result on the comparison analysis window. Once the input data are defined by the user, the system defines the methods/techniques which comply with the user preferences.

Consequently the system generates an overview window of the selected methods and for each one of them two links are given: a) description of the method; b) window where the elaboration of the method is applied to an example. This permits to the user to understand the technical background of each selected method and to confirm the choice for the last time. This is described as the first step of the "if, then, else analysis", which is based on a decisional tree process.

Once the above steps have been followed, the RC-k tool provides the main function of the system which consists of the Application Window. In this one, each method is listed with the related identification code along with the dependent parameters for its calculation. In this window the user inserts the input value of each parameter and the value of railway capacity is generated as an output data. The system provides a table (Fig.1) for each selected method.

The User has now two different options:

1) to perform a numerical comparison analysis of the capacity value which allows estimating the ability of the methods to deal with the typical operational situations and standards;
2) to generate a list of commercial tools that are available in the market: in fact RC-k is useful to present analogical simulation methods, which have found their natural market development; these instruments provide with an interface for dialogue with the user and simulate rail traffic. Usually they generate timetable graphs dynamically through specific algorithms. They can identify delays and analyze the interference in a predefined time. The detailed analysis carried out to date, as part of this research, has a total of forty 40 simulation environments.

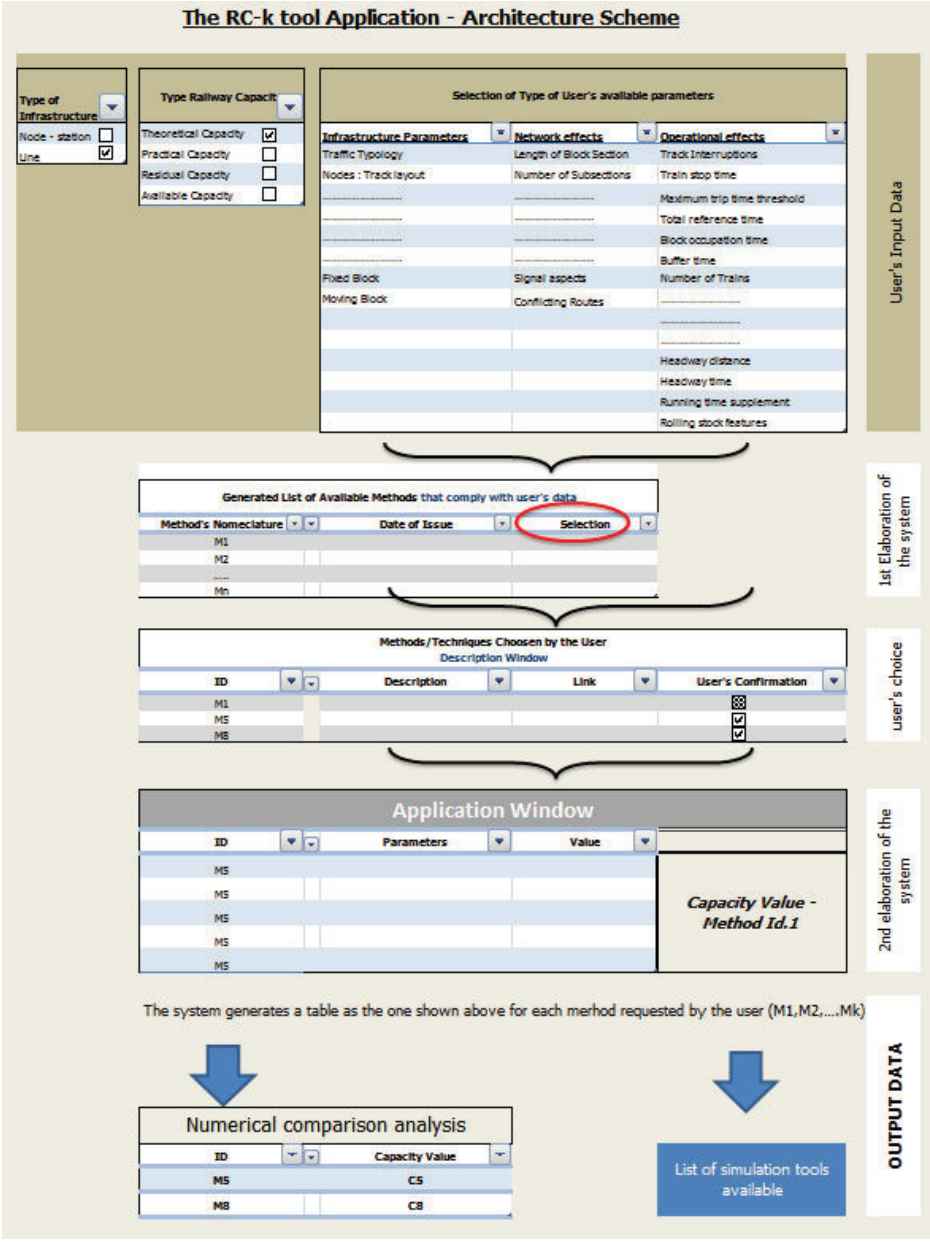

Fig. 2. The RC-k tool's architecture

4. Final remarks on strength, weaknesses and perspectives of RC-k

The RC-k application will be open on-line in the full version at the beginning of 2012. For each user a member code will also be available in order to generate a forum between users.

During the research period it RC-k has been assessed by main strengths and weaknesses, which may be summarized as follows:

- low cost web management: apart the initial decision activity and the general website maintenance, the other activities may be carried out by students interested to upgrade their knowledge;
- support to the development and use of capacity methods calculation by basic performances of personal computers;
- continuously updated database, at no cost;
- ambitious independent picture of worldwide transport capacity methodologies;
- simplification of information to be included in a very general scheme: positive in principle, but potentially dangerous if "the devil is in the details" and simplifications might hide relevant output;
- long term perspective to achieve a wide and consolidated role;
- need of voluntary activity to promote the involvement of an as largest as possible group of researchers and to let RC-k be more and more updated, upgraded and largely scientifically recognized.

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