TECHNIQUES AND METHODOLOGIES FOR RAILWAY CAPACITY ANALYSIS: COMPARATIVE STUDIES AND INTEGRATION PERSPECTIVES

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Summary: The article provides an analysis of methods and techniques for the qualification of the railway capacity, classified by reference to factors having a direct relationship with the obtained results. Synthetic, analytical and analogical methods are compared and developed.

Key words: Capacity, Methodologies, and Techniques.

1 Introduction

In an age where particular attention is focused on the best use, the maintenance and the technological adaptation of available resources, an important emphasis is played on the calculation of capacity in rail traffic. The continued growth of the rail transport demand leads to an increasing use of rail infrastructure, which often has a limited availability related to the topological configuration. Especially in the recent years the importance of quantifying the performance of the network in order to define the margins of railway capacity and define the availability has become an important theme.

The approach of the problem, very complicated because of several factors, has been analyzed in several ways. The existing methodologies have been developed since 1950 and have been progressively updated to current times. Several factors have given inspiration to this analysis, with the sole aim of offering a spectrum of choices and integration of different methods. Rail capacity, however, is a difficult concept to define and compute.

The difficulties are measured in a whole number of factors related to the complex structure of the rail system and the conceptual and terminological variety existing. In the present study all types of railway capacity are considered: Theoretical Capacity (TC), Practical Capacity (PC), Used Capacity (UC) and Available Capacity (AC). In this context, the ultimate goal of the present research, of which the first consolidated results are presented, is to provide a technical manual based on methods developed from the beginning of the 50's till today.

2 Study start-up

The themes proposed in this article are continuously evolving as the subject is wide and meets many developments and applications around the world. The part of this research inherent to the methodologies developed in Italy on calculating railway capacity has been completed and therefore it was considered that present a spectrum of this analysis could contribute to the technical knowledge in this field. This analysis will have its natural continuation with the deepening of the methods used abroad. The total number of

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methods is nearly to 40. Also the techniques of calculation based on previous works which, however, provided innovative contents, have been studied. These articles provided with much information, particularly data input and output of individual methodologies. A database has been created which is clearly not exhaustive, but has allowed, "comparing" all the aspects that are covered by the term "railway capacity". Where possible, the authors were also contacted to deepen the knowledge or request more clarification. The technical benchmark is completed by the application of the methods to a sample portion of the rail network. In particular, synthetic and analytical, optimization and simulation methods, including simulation environments (automated systems) have been considered.

Analytical methods model the railway infrastructure by means of mathematical expressions in a simple way that provides results of a first approximation, the optimization methods are based on research and best saturated schedules while simulation methods provide models capable of representing the reality in order to validate the timetable data. Referring to these, multiple products, which normally generate timetables by simulation using the laws of motion of trains are developed and then marketed.

The analytical computation is usually performed to obtain a first indication on the railway capacity in a preliminary state. It is applied through mathematical formulas and / or algebraic expressions. The simulation environments are tools on the market that dialogue with the user interface and simulate rail traffic. Usually they generate timetable graphs dynamically defined through equations in which the time is a fixed variable in defined intervals. They can identify delays and analyze the interference in a given time. A detailed analysis was carried out on a total of twenty simulation environments so far.

Further step of research will take place with the formulation and development of an integrated instrument characterized by different degrees of detail, therefore, useful for academic, technical-scientific and operational scopes.

In this article, we propose a first part of the results concerning only methodologies formulated in Italy.

3 Definitions

3.1 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, we must introduce the concept of nominal capacity of the transport system, also called transport capacity. This term may be referred to both the two environments making up the rail system: lines and nodes.

3.2 Relevance and definition

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, it is not possible an unique definition.

4 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 lay-out's;
- Features of signaling systems;
- Movement rules and corresponding minimum distance between trains;
- Operation and maintenance planning

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 expressed 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.

5 Parameters determining the carrying capacity

5.1 Variability and relevant parameters

Capacity is dynamic and closely linked to the elements that make up the rail system. They have an inherent variability, which is translated into a variation of the same capacity for different train typologies and performances and time allocated, the state of infrastructure and means of operation. In this analysis the main parameters affecting the determination of capacity have been considered: infrastructure parameters, operational parameters and traffic effects.

5.2 Infrastructure parameters

4.2.1 Number of Tracks

On single-track lines, the section characterized by the highest travel time between two adjacent stations or intersections, is considered. On double-track lines a similar approach may be followed, with the caution to consider separately the trains of both direction and related sections of largest travel time that may not be coincident. Therefore the first fundamental distinction in the methodologies developed is due to single/double track. The calculation approach is nevertheless different because in the case of single-track lines the possible promiscuous movement of the two traffic directions requires higher safety margins. Many of the proposed methodologies only address the case of single-track lines neglecting its extension on double-track lines and vice versa. The result is a discrepancy between the different methods and a lack of uniformity of these methods on two types of lines.

4.2.2 Distance between two crossing or passing stations

The distance between two stations with crossing or passing loops is a parameter of primary importance. In fact it characterizes the section block and consequently affects the whole line. The block section defines the theoretical number of trains that can move through a line.

4.2.3 Total reference time

Methodologies and techniques normally refer to the whole day or peak periods. In the progressive evolution of these methods off-line time due to planned and unplanned maintenance was added. Therefore the capacity over 24 hours is normally overestimated.

4.2.4 Theoretical speed and project speed

Theoretical speed is the one prescribed by the infrastructure manager on the basis of traffic modules allowing accurate dynamic characteristics of rolling stock.

The project speed is the speed with which a train can travel along a line section according to geometric features and state of the maintenance of the line.

5.3 Operating Parameters

4.2.1 Operational model

The operational model, intended as paths occupied by trains on the time-space frame, in addition to the technical specifications of temporal and spatial separations between trains required for crossing and overtaking operations, determines the travel time required by each train. Methodologies and techniques for the determination of capacity are distinguished, in this respect, into two main categories: those taking into account the number of scheduled trains and calculating the remaining capacity and those calculating an average travel time for trains and, therefore, getting an overestimation of the capacity itself.

4.2.2 Rolling stock features

The characteristics of both traction and braking curves and the composition of the trains determine the running time, the resulting required stopping distance and, therefore, headways and allowed speed according to the geometrical features of the line and the possible ability to partially compensate onboard the transversal acceleration.

4.2.3 Traffic typology

The traffic typology is defined as the distribution of different rolling stock assets running on a line. The different performances of trains reflect on the allowed speed, normally defined in speed classes. Many authors considered this fundamental aspect by expressing the variation of the capacity depending upon the speed classes.

4.2.4 Headway

The spatial distance between two following trains and therefore the length of the block sections determines the maximum traffic intensity from which the capacity itself is depending. Many authors dealt with the relationship between headway and capacity with the adoption of a system rather than another [21] [18]. The number of trains increases as short as the intervals between them are and on the lines with block systems allowing more than one train between two stations.

4.2.5 Operating Effects

Generation and Propagation of delays

The delay produced by any conflict may depend upon the following factors:

- Difference between the speeds of conflicting trains;
- ·Minimum distance between two trains;
- Distance between two following stations and number of tracks available for crossing and overtaking operations;

- Priority rules for running;
- Time for routes maneuvering and releasing in the stations.

4.2.6 Required and expected quality of service

The quality of service required normally depends upon the traffic typology and the requirements fixed in the agreements between infrastructure managers and train operators. In Italy these requirements reflect on priority rules for rail traffic management issued by the infrastructure manager.

6 Application

As previously mentioned, the methods were applied for comparative purposes to the critical section of the railway line Sapri - Paola, between Cetraro and Fuscaldo stations, for an overall length of 13.2 km. The applied methods made possible to calculate a set of values of theoretical capacity, expressed as trains per day, including over a wide range and in some cases significantly different from each other with values ranging between 100 and 170 trains per day for each direction (Figure 1). It is pointed out how the values of the capacity have the same order of magnitude for the methodologies by Bianchi (1964) and the FS formula (1968). In fact, these are easy to apply but have the limitation of not considering perturbed traffic and not homogeneous speeds. In fact by including these two factors Bianchi, in his second formulation, significantly reduces the value of the theoretical capacity. DB and UIC formulas introduce elements explaining the influence of speed classes' alternation in the actual operation by providing lower values of capacity. The remaining methods, with the single exception of Cascetta and Nuzzolo method, lead to define capacity values in a similar order of magnitude, anyway depending upon the multiple parameters taken into account. The high capacity values calculated according to Cascetta and Nuzzolo method mainly depends upon the introduction of several new factors normally decreasing capacity as proven by more recent methods considering them.

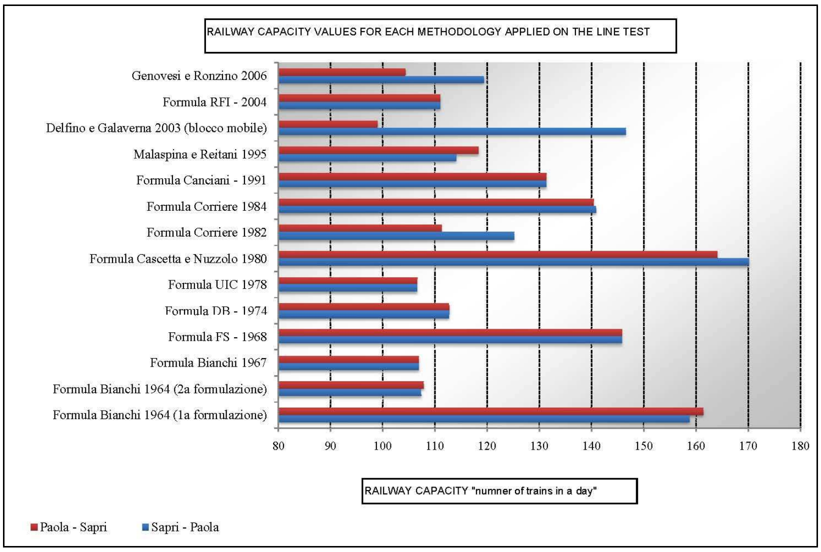

Fig.1: preliminary results of a comparative analysis carried out on the above methodology and to the critical section of the railway line Sapri-Paola.

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