

A Review on Railroad Capacity Assessment Techniques

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ABSTRACT: A continuous growth in freight and passengers demand creates a pressure to increase the capacity of Railway networks. Due to the limited infrastructure of Railways demand can be fulfilled only by managing the capacity efficiently. So, researchers moved their focus on capacity expansion techniques. In this paper, the concept of capacity and main capacity assessment techniques are assessed. This paper gives more attention to modelling parameters and findings and gives less attention to mathematical models and solution procedures.

KEYWORDS: Capacity, UIC-406, Simulation.

I. INTRODUCTION

According to Transportation Research Board (TRB), Line capacity is the maximum number of trains that can be operated over a section of track in a given period, typically one hour [1]. The International Union of Railways (UIC) mention that the definition of capacity depends on the way of utilization. If it is market-oriented, then it must be satisfied the peak values of expected number of train paths and traffic mix while infrastructure planners take average values for cost-effective use of infrastructure. When capacity is timetable oriented, then it considers infrastructure and existing train paths together. When capacity is looked at the operational point of view, then it would satisfy the present infrastructure availability, and manage delays and an additional number of trains. So, the capacity definition can be modified according to use.

The objectives of capacity calculation can be divided into two parts: primary objective, which are basics and desirable conclusions of the capacity calculation and other part is secondary objectives, which fulfill associate targets of capacity improvement.

TABLE I. OBJECTIVES OF CAPACITY CALCULATION

Primary objectives	Secondary objectives
-Making the best use of capacity that is potentially available	-Maintaining the service quality by limiting the number of trains
-Maximize the number of trains that can be operated, subject to constraints imposed by service mix, stopping patterns, etc.	-Reduce the conjunction delays
-Reducing the capital and operating costs.	-Generate the largest revenue
-Planning of new lines	-Analyzing the effect of different parameters on capacity
	-Find and eliminate the bottlenecks in a rail line to use the maximum capacity

II. TECHNIQUES TO CALCULATE RAILROAD CAPACITY

Many approaches have been developed to determine the railway capacity. Each approach is significant for a particular application thus they are developed in different infrastructural and operational conditions. Various parameters and constraints chosen in these approaches also separate them from each other. Some techniques quickly emulate railway

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operations and provide an approximate solution that can be useful in the planning phase [2]. Some models are complex in practice but give precise results that are useful from a business point of view. The methods for capacity calculation can be categorized into four sections as analytical, parametric, optimization and simulation models [3], [4], [5].

1. Analytical models

These models are easy to use and have less mathematical calculations so, provide solutions quickly. These models are suitable for planning phase. Poole developed a mathematical formula to measure maximum capacity of the single-track line [6]. Mirko Cicak and Dragomir Mandic calculate the capacity utilization of Yugoslav Railways regarding oscillation coefficient [7]. Two well-known capacity analysis methods CUI and UIC-406 methods come down under this category.

A. CUI Method

Capacity Utilization Index (CUI) method is based on the timetable compression rule. The timeline is compressed according to minimum headway distance as shown in figure 1. Gibson defined the CUI as the ratio of compressed time (B) to actual time (A) of the timetable graph [8].

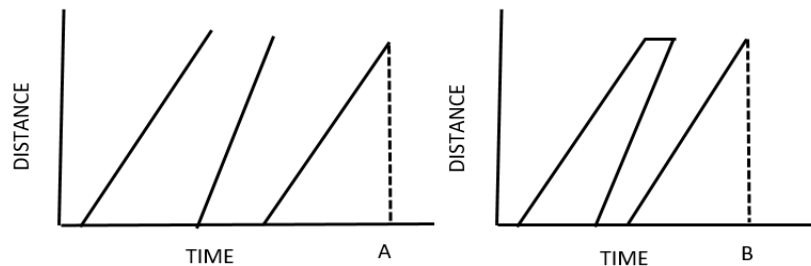


Fig. 1. Timetable compression according to CUI method

The CUI method is more popular in British operating context because it is based on Timetable Planning Rules (also known as Rules of Plans) which were produced by Network Rail (owner and operator of British Rail). Faber Maunsell also illustrated the process of CUI calculation [9].

B. UIC-406 Method

In 2004, the International Union of Railways proposed UIC-406 method for the capacity calculation [10]. This method was also based on timetable compression process as shown in figure 2.

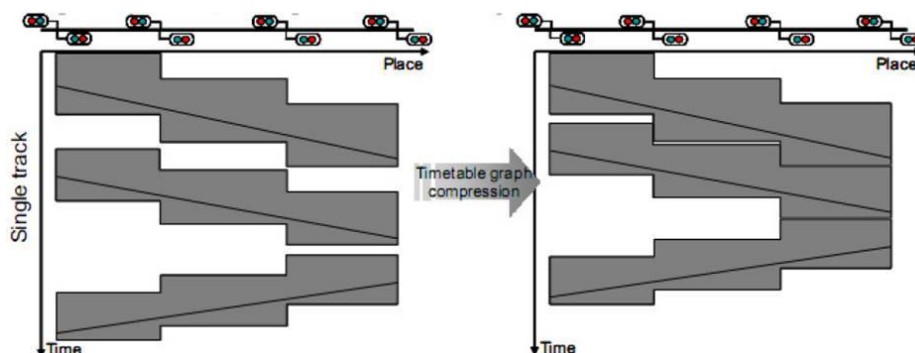


Fig. 2. Time-table compression according to UIC-406 method

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The difference in CUI and UIC-406 method is that CUI method is applied at route section level while the UIC-406 method is applied at the signal block level. The drawback of CUI method is that it can be used only at the macro level so it gives a broad estimation of capacity and there is no provision to access the nodal (e.g., station) capacity. Armstrong et al. tried to remove the drawbacks of CUI method by extending the applicability of CUI method from network links to nodes [11]. He showed with examples how to handle complex capacity assessment problems.

Robert Prinz used the UIC-406 method to calculate the capacity consumption on Australian railway lines and experienced it effectively [12]. He concluded that the method is more influenced by hard facts like infrastructure, existing time table and little influenced by other factors, such as priorities, the current level of quality, etc.

Landex expounded the UIC-406 method in different ways in Denmark [13]. He explained how to choose the correct length of line section and how to calculate the capacity consumption for two or more tracks. He suggested not dividing the railway line into line sections at the overtaking because it leads to more capacity utilization and train orders remain the same during compression graphs at both ends of line section to avoid additional overtaking.

Lindner found problems with applying the UIC-406 method to assess the capacity of the station because the code concentrates only on line sections and does not give the procedure to find station capacity [14]. The code also does not dictate how to choose the correct length of line sections in case of longer sections of single track with many sidings which are very common in North American railroads. Lindner suggested using the virtual traffic diagram method rather than the original timetable to get more realistic results. He also advised UIC to demonstrate the capacity calculation procedure for mixed traffic patterns.

Jiamin Zhan et al. developed a framework for calculation and assessment of Chinese High-Speed Railways (CHSR) [15]. This framework was based on UIC-406 code but uses the plan of operation instead of a current timetable to calculate the capacity of line section or station.

2. Parametric models

In parametric models, basic infrastructure and operational parameters are used for capacity. Prokopy and Rubin developed a multivariate regression model to analyze the effect of various operational parameters on train delays [16]. Krugner also followed Prokopy and Rubin and explored the railroad capacity with the help of entirely different parameters [3]. He divided the parameters into three categories: plant parameters (length of subdivision, meet-pass point spacing, signal spacing, percentage of double track), operation parameters (track outages, temporary slow orders, train stop time, maximum trip time threshold), and traffic parameters (traffic peaking factor, priority probability, speed ratio, average minimum run time). Delay was chosen as a capacity measure. The model was capable of determining line section capacity and was also useful in sensitivity analysis of parameters.

Mitra et al., and Muraliet al. modified the Prokopy and Rubin's model and estimated the critical parameters that affect the railroad capacity [17], [18]. Lai and Huang modeled the problem with some of the basic parameters, simulated and then validated with regression analysis and neural networks and found critical factors for capacity [19].

Parametric models are seen to bridge the gap between analytical and simulation models as they use more data than analytical models to give more accurate results, but exhaustive simulation work is diminished so provide quick solutions. However, parametric models are not popular as others because they provide only a single estimate to judge the performance. In most cases, delay is chosen as a performance measure which is insignificant in all situations [20]. Parametric models also don't have the capability to provide the comprehensive analysis of individual trains as possible with simulation models.

3. Optimization models

Optimization models give the strategic solutions of concerned problems. Asad reviewed the capacity calculation techniques before 1980 [2]. By using branch-and-bound method, Jovanovic and Harker solved a mixed-integer linear programming model for a feasible schedule [21]. Harker also studied the economic impact of timetable scheduling and introduced a computable equilibrium model of an internal market for track resources. [22], [23] illustrate heuristic-driven approaches to obtain capacity objectives.

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[24], [25] developed fast algorithms for rescheduling problems. Oliveira and Smith model the problem as a job shop scheduling problem [26]. They consider the trains as jobs which are to be accommodated on Railway paths. Jia et al., Milinkovic et al. used the Petri Net to measure the node capacity [27], [28]. Masod Yaghini performed a study on Iran Railways and presented Discrete-Time-Multi-commodity network design model to find the impact of train types on railway capacity [29]. Lars Wittrup Jensen solved an optimization model with greedy heuristic and access that how many trains can be added to network up to the threshold limit [30]. Francisco A. Ortega Riejos developed some fast algorithms for capacity calculation [31].

4. Simulation Models

Simulation models generate the solutions by the imitation of process over the time. These models are dynamic and provide more precise results than other methods. These models are used as combinational approaches with other methods or in the form of complete simulation packages. In combinational models, results are obtained by analytical or optimization methods and are refined by simulation process. These models are also used as a tool for validation of optimization results.

Petersen combined the dynamic programming and branch-and-bound in a simulation context [32]. Welch and Gussow combined simulation and heuristics to evaluate the relative effectiveness of the many factors that influence line capacity [33]. [21], [34], and [11] combined the simulation with optimization to access used capacity.

Simulation packages are helpful in academic as well as in rail industry to an extensive analysis of rail operations. [4], [35], [36] presented a broad survey of railway simulation packages.

Dingler et al. analysed the impact of heterogeneity, acceleration and braking conditions and, the priority of trains on capacity [37]. He chose delay as the capacity metric and simulated various infrastructure scenarios with the help of Rail Traffic Controller (RTC) simulation package. Shih et al. also used the RTC and found the solutions for best capacity expansion strategy [38]. Hamed Pouryousef et al. used the RTC and RailSys to establish the relationship between the level of service and capacity utilization [39].

III. CONCLUSION

This paper examines a significant number of research papers and explains the concept of Railroad Capacity. Various objectives of capacity calculation are defined, and different techniques are reviewed to achieve these objectives. Analytical methods are found the best fit for the planning stage of a Railway project. Optimization methods are used extensively to provide the strategic solutions. Parametric models are also suitable for both planning and operational stage. Simulation models take much time to provide the solutions but give reliable results.

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