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Influence of Signalling Systems on the Capacity of Railways by Lines and Nodes Assessment Methods

Uzgidim Ömür Cansu[a], Kianinejadoshah Atieh[a]*, Ricci Stefano[a]

[a] *Department of Civil, Building and Environmental Engineering, Sapienza University of Rome, Italy*

Abstract

In the complex railway networks characterized by mixed traffic, a key focus is the increase of railway capacity by high-performance signaling systems, including ETCS/ERTMS and beyond. Nevertheless, the estimation of effects on the headway of the introduction of innovations in signaling systems is not consolidate for complex networks.

This study highlights several challenges in the line-node capacity calculation of congested networks considering a combined effect of routes conflicts in the station on lines and propagation in stations of delays suffered along the lines. The paper describes some results of the ongoing research based on the integrated use of analytical methods and simulation to networks controlled by different standard signaling systems and able to increase the capacity under specific operational conditions.

The paper introduces the application of the methods to the complex mixed-traffic network nearby the Trieste railway node, situated in Northeastern Italy, including the main passengers and freight terminals and the lines operated for both services. The objective is to identify the most appropriate technological solutions and methodological approaches for the optimization of the network capacity and the minimization of delays.

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Keywords: capacity; signaling; timetabling; simulation

* Corresponding author. Tel.: +39-0644585142.
E-mail address: Atieh.kianinejadoshah@uniroma1.it

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1. Introduction

Over the last decades, railway transport has experienced an increasing trend around the world, especially in developing countries, where demand for rail transport has dramatically increased. Therefore, particular attention is necessary for the quantification of network performances, identification of bottlenecks and definition of margins of railway capacity, focusing on the most effective factors, such as timetabling and signaling, to operate more trains securely run on the network.

Timetabling is a well-known optimization problem in railway operations (Gestrelius et al., 2021) the railway timetable is a tactical level planning document, typically revised on a yearly basis. However, the fluctuations in goods volumes and other factors that not estimated in the annual timetabling process, affect the departure time punctuality of freight trains (Erlandson et al., 2021) with higher likelihood of delays among freight trains than among passenger trains. The intervals between consecutive trains are smaller for a higher traffic volume, which makes increase the traffic volume increase and they delays propagation: it is more likely that one trains' delay impacts other trains' punctuality as well (Haehn et al., 2020). In order to employ effectively the railway capacity, the timetable structure must contain intelligence providing the required robustness and neutrality across service market segments and operators (Gestrelius et al., 2020). Railway capacity analysis of a specific timetable aims to assess the number of trains reasonably operated on a given infrastructure (Johansson & Weik, 2021).

Signalling systems manage railway traffic and keep trains clear of each other at all times. Compatibility becomes increasingly difficult with high traffic density and the distance between two succeeding trains reduces, while a delay increases the likelihood of conflicts at specific points (Weik et al., 2020). The introduction of Block Systems (BS) with short sections, which allow for a reduction in the minimum distance between two succeeding trains, is a point to consider (Landex & Jensen, 2019). The innovative technological block system ERTMS/ETCS has the potential to increase the capacity of node and lines by reducing the minimum distance between two successive trains while imposing no significant restrictions on train operation (Pachl, 2021).

The purpose of this paper is to study the factors affecting the capacity by applying the analytical methods for station timetable optimization, originally proposed by (Müller, 1960) and (Giuliani et al., 1989). The assessment of the upgrades of ATC2 line signaling system to ETCS Level 2 is validate by the OPENTRACK® simulation software (Nash & Huerlimann, 2004) estimating occupation times, minimum headways, delays and conflicts in a complex network.

2. State of the Art

Capacity calculation assessments base on lines, nodes and combined line-node methods (Kontaxi & Ricci, 2009) (Kontaxi & Ricci, 2011) offered a rich bibliography of existing methodologies developed since the 1950s and progressively updated mainly considering the combined line-node methods (Kianinejadoshah & Ricci, 2021). In addition, the influence of the ERTMS signalling system on capacity have studied for years. The results demonstrate that the higher ETCS levels increase the capacity, e.g. in (UIC, 2008) and (Landex & Jensen, 2019).

2.1. Combined line- node capacity

Traditionally, the line models require the knowledge of the train succession and the node models base on the hypothesis of independence by the surrounding lines. The formalization of the effects of the interaction between the network elements (lines and nodes) and the link between carrying capacity and system characteristics are in (Rotoli et al. 2016). Some studies (Crenca et al., 2005) and (Crenca et al., 2006) evaluated the effects of infrastructure and operational improvements fully using the capacity. The last version of Code 406 (UIC, 2013) described the extension of the capacity method to the station and extended line segments including overtaking (Weik et al., 2020). The most recent synthetic methodologies (Kianinejadoshah & Ricci, 2020) (Kianinejadoshah & Ricci, 2021) describe a comprehensive approach for combined node-lines capacity calculations of complex railway networks.

2.2. Signalling system

Capacity is a complex concept affected by factors, such as infrastructure, train timetables and rolling stock. This work considers the capacity features that lead to variations in capacity, such as signal distances, braking curves and response times of the system.

The European Rail Traffic Management System, which is a standardized signaling system, has two main components: ETCS (The European Train Control System) and GSM-R (Global System for Mobile Communications-Railways). ETCS has three different levels based on the update of the movement authority (signal aspect) (European commission, 2001).

Some studies have analyzed the capacity differences among signaling systems, including the ERTMS/ETCS Levels, using the headway calculation model, e.g. (Landex & Jensen, 2019).

In order to investigate the impact of ERTMS/ETCS on line capacity, the result of studies based on UIC 406 (UIC, 2008) demonstrate that Level 2 generally has shorter headways than Level 1 and the traditional signalling system and, hence, higher capacity. In particular, the more homogenous the traffic, the greater the capacity benefits are (Landex & Jensen, 2019).

2.3. Simulation

Nowadays, a variety of simulation tools are in use for analyzing timetabling processes affected by a variety of variables or randomly created irregularities in the train traffic (Halás et al., 2012). After an extended and comprehensive investigation carried out some years ago, the categorization of synchronous micro-simulation tools are in (Kontaxi & Ricci, 2010) and, for the commercial tools RailSYS© (Lindfeldt & Sipilä, 2014), VILLON® (Adamko & Klima, 2008) and Trenissimo® (De Fabris et al., 2018).

OPENTRACK® is one of the most accurate, widely applicable simulators to determine the performances of a railway network, analyze the capacity of lines and stations, as well as the robustness of timetables improved by the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT) (Nash & Huerlimann, 2004).

Moreover, an example of synchronous microscopic simulations is CAPRES, developed by ITEP-EPFL in partnership with the Swiss Federal Railways, to provide planners by designing and saturating network timetables, allowing them to assess the capacity of the network along the process (Lucchini et al., 2001). DEMIURGE is a tool for railway infrastructure and timetable optimization, as well as capacity assessment of any component of the train network (Labouisse et al., 2001). FALKO software aims the construction and validation of timetables for railway systems (Siemens AG, 2007). FASTA is a comprehensive software package for the simulation of trains running on a highly interconnected network. Its main purpose it to provide information needed to assess the stability of the alternative timetables (Allan, 2008). IRSIM is a software for investment in railway capacity increase applied in Slovenia (Kianinejadoshah & Ricci, 2021). RailSys is the microscopic simulation current standard tool for railway simulation to provide the detailed planning of alternative infrastructures and timetables (Johansson et al., 2022).

3. Case study applications

This research focuses on a real complex mixed-traffic network in the Trieste railway node, situated in Northeast Italy, including the main passengers and freight stations and a set of lines used for both services. The railway line is broken down into two sections (Fig. 1):

a) First section: from Trieste Centrale and Trieste Campo Marzio to Bivio D'Aurisina;
b) Second section: from Bivio D'Aurisina to Udine.

3.1. Analytical method

The Müller method is proposed for the large railway nodes with the aim of evaluating the potential of a station system using synthetic indicators and measuring the variability of these indicators and therefore the response of the system to the perturbation. The following assumptions apply to the present research:

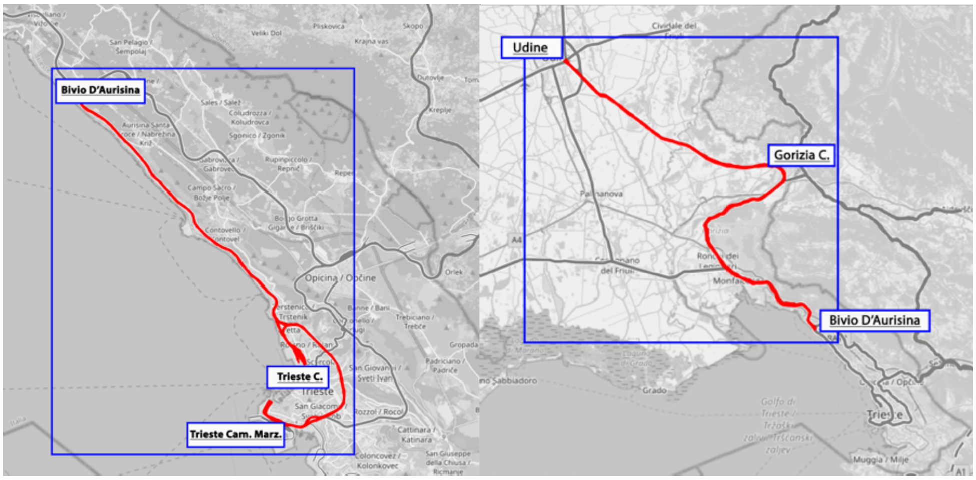

Fig. 1. (a) First Section; (b) Second Section

- Reference time: 18 hours;
- Dwell time: 1 minute;
- Average speed along the line: 60 km/h;
- Average speed at junctions: 30 km/h;
- Paths categorized according to the destination and can use as the alternative for the train dispatching;
- Departure time from the origin station based on the planned timetable available online;
- Overall buffer is the average of the entrance and exit buffers;
- Passengers train departed from Trieste Centrale, meet the freight trains of Trieste Campo Marzio at the Barcola Junction and continue along the double-track line;
- Freight trains without stops;
- Traditional signaling system.

Thanks to the output provided by the Müller method, the optimized timetable is usable as an input for the simulations.

3.2. Simulation method

Simulation helps to evaluate the capacity of specific parts of the railway infrastructure by considering traffic characteristics. Moreover, the results obtained by simulation are not explaining the capacity of the line as such. Simulation produces an analysis of specific operating scenarios, the stability of the proposed timetable and the identification of bottlenecks in the network. For these reasons, several possible operational scenarios should ensure for generalization purposes (Tischer et al., 2019). The created simulation model include:

- Simulating of the infrastructure of the : profile, safety device, speed profile;
- Creating train sets of selected train categories;
- Inserting train paths, routes and other elements of the traffic schedule;
- Progressive simulation of operations;
- Simulation of scenarios;
- Collection of results and final evaluations.

ERTMS consists of five different levels: Levels 0-3 and Level NTC (National Train control). The NTC allows trains equipped with ERTMS to run on infrastructure that requires the use of the national train control system. ETCS Level 1 is the most traditional system with Automatic Train Protection (ATP) (Landex et al., 2019) with discrete update, while level 2 has continuous update of the Movement Authority (MA), based on fixed block sections (European Commission, 2019). When a train passes through Euro-Balises, the MA updates. The system needs the use of visible signals as well as the detection of track section occupation. The on-board computer continuously analyses the data and uses it to calculate the maximum speed and braking curve. The interoperability of providers and countries is the key benefit of ERTMS/ETCS level 1 (ERTMS, 2019). In ERTMS/ETCS level 2, the MA transmission from a radio block centre (RBC) by using the GSM-R network is continuous. The system detects the track section occupation by train using axle counters, but signal visibility is not necessary. Continuous data transfer provides improved capacity to discrete update of the movement authority in level 1, allowing the train to reach its optimal speed maintaining a safe braking distance (European Commission, 2019) and (ERTMS, 2019).

In order to investigate the different block signalling performances, OpenTrack simulation software applies the blocking time method to calculate train headway, based on calculating the amount of time a train reserved to a single train path by blocking it from other trains (UIC, 2008). The acceleration and deceleration of trains, as well as dwell time at stations allow calculating the block occupation times (Pachl, 2021). Ramboll has created a model that calculates minimum headways based on the positions of the signals, release points and switches, speed profile of the line, characteristics of rolling stock, signalling dependent braking curves, route set and release times and communication delays between trains using the blocking time method. Two marker boards or main signals for traditional signalling limits a block section. The UIC found out that improved block sections lead to significant higher capacity (UIC, 2008). The longest stopping distances by the fastest trains determine the length of the block sections (Landex et al., 2019). Improvements of the block sections from the current signalling layout are obtainable by locating marker boards at existing signals, adding extra block sections on selected stations respecting location of switches.

This technique uses the current location of traditional signals as a starting point (scenario 1). By creating layouts upgraded to ERTMS/ETCS Level 2 (scenario 2), current situation and ERTMS/ETCS Level 2, with improved block sections and proper trains, are comparable and assessed based on headways and capacity consumption calculated using the blocking time model. The following assumptions apply to the present research:

- 67 km double track line from Bivio D'Aurisina to Udine;
- Standard signalization (ATC2);
- Mixed traffic (passengers and freight);
- Upgrade to ERTMS/ETCS Level 2;
- Reference time: 18 hours;
- Departure time from the origin station based on the real timetable.

4. Capacity results

The capacity analyses carried out in this study are both general and applied to a case study represented by the line between Udine and Bivio D'Aurisina. The considered scenarios base on occupation time, headways calculation and upgraded timetables.

The developed simulation models demonstrate to be useful and effective tool to compare different signaling systems in terms of headways and capacity. On these bases, capacity consumption estimated using the blocking time model, the current situation and the ERTM/ETCS Level 2 with better block sections are finally comparable. Figure 2 and Table 1 show that ERTMS/ETCS Level 2 generally present a shorter occupation time compared to the current situation due to the reduced delays.

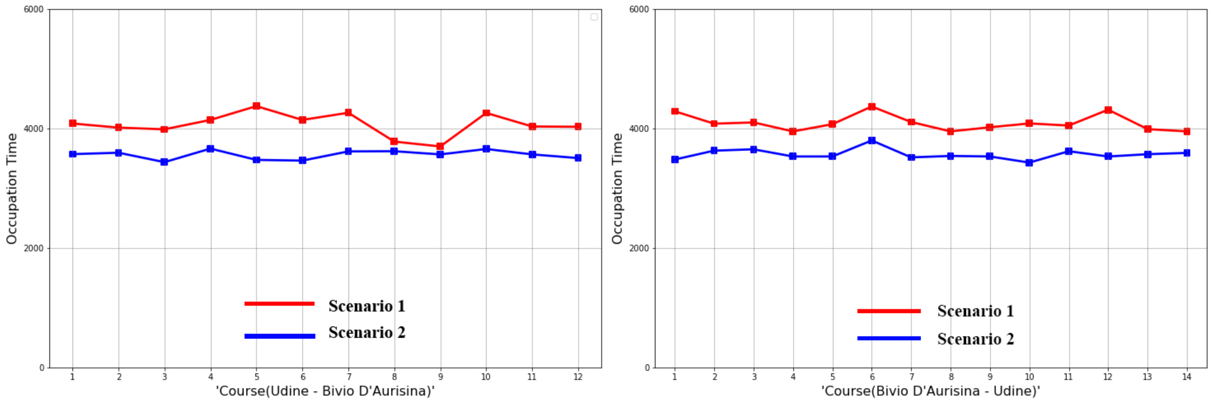

Figure 2: Occupation time comparison from Bivio D'Aurisina to Udine

Table 1: Average Occupation Time and Reduction

	Udine-Bivio D'Aurisina		Bivio D'Aurisina-Udine	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Average occupation time [s]	4067	3560	4095	3560
Reduction [%]	12.45		13.04	

Figure 3 and Table 2 compare headways in scenarios 1 and 2.

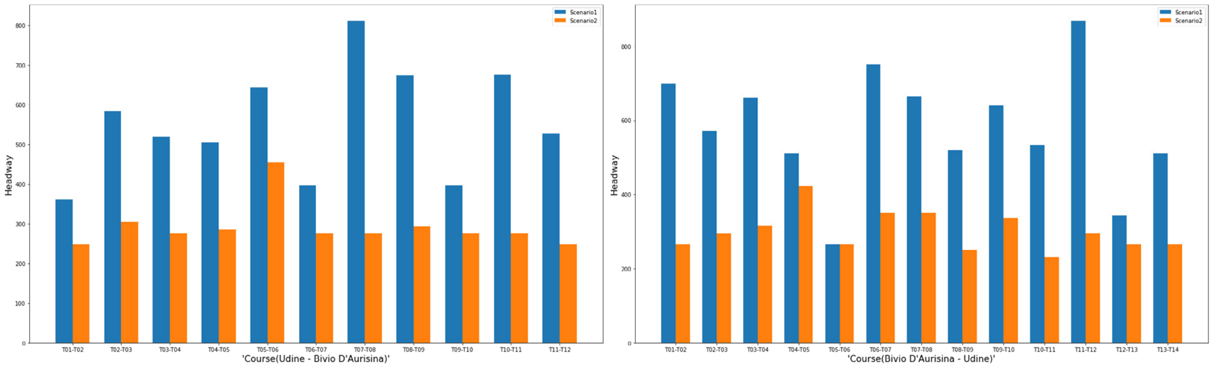

Figure 3: Comparison of headway in scenario1 and 2

Table 2: Headway indicators and Reduction

	Udine-Bivio D'Aurisina		Bivio D'Aurisina-Udine	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Min. Headway [s]	361	248	344	232
Reduction [%]	31		43	
Max. Headway [s]	811	455	868	423
Reduction [%]	32		51	

Meanwhile with ATC2 the visible limits the location signals and the block sections should be in line with the braking distance, ERTMS/ETCS Level 2 does not have the same limitations and can implement shorter block sections, which can improve the capacity.

In the case study, the occupation time reduces by 12-13% and the minimum headways calculated decreases by 31-43% for the two directions.

5. Closing remarks

The capacity analyses carried out in this study are both general and applied to a case study represented by the line between Udine and Bivio D'Aurisina. The considered scenarios base on occupation time, headways calculation and upgraded timetables.

Meanwhile with ERTMS/ETCS Level 1 the signal visibility limits their locations and the block sections should be adjusted with the braking distance, ERTMS/ETCS Level 2 does not have the same limitations and can implement shorter block sections which can improve the capacity.

In the case study, the occupation time is reduced by 12-13% and the minimum headways calculated by the built simulation model decreases by 31-43% for the two directions.

Additionally, the simulation allows the analysis of the compressed blocking time diagrams to identify possible conflicts and delays and to obtain conflict-free timetables.

The results show that ERTMS/ETCS Level 2 is able to provide with shorter headways and occupation times compared with the current situation. The combination of shorter block sections and continuously updated Movement Authority produce relevant increases of the capacity.

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