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# Railway Line Capacity Relative to Additional Block Division

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## ABSTRACT

The article discusses the results of studies of railway line capacity relative to the application of additional block division using virtual blocks in the process of positioning a train reporting its position and train set integrity. The studies were conducted using the authors' original simulation software enabling extensive parameterisation of infrastructure, including configuration of the train control system and signalling principles, by taking the actual characteristics of train movements into account based on data obtained from real-life measurements.

## KEYWORDS

railway capacity; ETCS, simulation; MATLAB; Simulink.

## 1. INTRODUCTION

Having deployed the ERTMS/ETCS Level 3 system, one can manage safe separation between trains based on moving block sections. Trains are detected using the reported train position and the reported train set integrity [1, 2]. Introducing the moving block system into a railway network may entail a significant technical and organisational change. Bearing the foregoing in mind, one may consider some intermediate solutions making it possible to gradually pursue new operational principles and technical readiness within the framework of moving block section-based traffic management.

One of such intermediate solutions is the application of an additional division of conventional block sections (with trackside train detection systems) using virtual block sections. Virtual block sections can become an additional element of the existing block section division system [3]. This makes it possible to expand the block section division system without the need to install additional trackside equipment while enabling the traffic of trains which do not report their train set integrity to be managed [3]. What this configuration also allows is an evolution, rather than a revolution, in terms of traffic management principles and degraded situation handling. The solutions which include the additional division based on virtual block sections are referred to as ETCS Hybrid Level 3, ERTMS High Density or Hybrid Train Detection solutions [3, 4]. Another alternative entails using conventional non-occupancy sections to determine blocks with lengths suitable for the traffic to be managed under the ERTMS/ETCS Level 2 supervision, which may prove advantageous where a significant fraction of the rolling stock does not have technical capabilities to report train set integrity, e.g. train car sets. Irrespective of the solution implemented, the application of an additional block section division concept should be preceded by analyses and studies aimed at achieving maximised railway capacity assuming a given configuration of the railway traffic control system and signalling principles which can vary among different countries [5, 6]. Available commercial tools for capacity assessment using simulation methods do not always provide the opportunity to evaluate new signalling concepts, particularly when taking into account local signalling principles and requirements.

It is precisely for this reason that the authors have proposed original simulation software, developed in the Matlab&Simulink environment, which can be employed to assess the capacity of a railway line featuring diverse configurations of railway traffic control systems. In Chapters 2 and 3, the existing methodologies for assessing railway line capacity have been analysed, and the impact of the signalling system on capacity utilisation has been presented. By utilising proprietary simulation software, assessments of three distinct configurations with virtual sub-section divisions have been presented in Chapter 4. Chapter 5 presents the obtained results, while Chapter 6 comprises the discussion, summary and considerations for future work.

## 2. RAILWAY LINE CAPACITY ASSESSMENT METHODS

Capacity assessment methods can be divided into analytical, optimisation and simulation methods [7]. Analytical methods for studying railway line capacity focus on using mathematical and computational techniques to assess the efficiency and limitations of rail networks [8]. We can distinguish between simple analytical methods for initial capacity assessment (based on time occupancy of defined block section) and more complex ones based on stochastic techniques and queueing theory [8, 9]. Optimisation methodologies offer significantly superior solutions compared to purely analytical formulations [8]. The optimisation of specific parameters frequently necessitates the pursuit of either minimum values (e.g. delays, travel times, costs) or maximum values (e.g. train quantities, service reliability, quality) [8]. A preeminent optimisation approach is expounded in UIC-406 [10], entailing an iterative protocol involving the compression of the extant timetable distribution and supplementation with supplementary train services, as if the trains were to operate within minimal temporal intervals. These optimisation strategies are grounded in aggregate input data, often associated with train traversal attributes within distinct train categories, whether passenger or freight, with limited consideration for disparities among individual vehicular classifications. Simulation methods which make use of computer modelling techniques, enabling railway traffic to be simulated against the railway infrastructure, make it possible to determine the railway line capacity by considering the characteristics of the simulated objects, i.e. trains, the train control system and signalling principles. Simulation tools are broken down into microscopic and macroscopic models. The choice of analysis level should depend on the specific objectives of the analysis. For instance, when analysing signalling equipment, it is advisable to primarily concentrate on the microscopic level, where signal points are represented as individual nodes [13]. What the microscopic tools take into account is the details of the infrastructure and vehicles, while the macroscopic models are simplified and are suitable for network studies based on the graph theory [7] [8]. There are several commercial software tools available for the assessment of railway capacity, such as OpenTrack, RailSys, OpenTrack [11–13]. All of these mentioned tools are rooted in the principles outlined by the UIC-406 methodology [11, 12]. The simulation of train dynamics within these tools is founded upon the integration of vehicular data, encompassing variables such as the traction characteristic (described as the relationship between tractive force in kN and velocity in km/h) and rolling resistance [11, 12]. Nonetheless, it should be acknowledged that these data might not consistently facilitate an exact replication of train motion characteristics, given the potential for the dynamic modulation of traction attributes within rolling stock through contemporary propulsion control systems [17]. Concerning the simulation of infrastructure and railway traffic control systems, RailSys offers the capability to replicate train operations under the purview of the European Train Control System (ETCS) at Levels 1, 2, and 3, alongside traditional wayside signalling systems that possess the requisite reliability. However, it is crucial to emphasise that these software tools have primarily been designed in accordance with the signalling methodologies prevailing within their respective countries of origin. While adaptation to signalling protocols of alternate nations is conceivable, achieving complete correspondence may not always be realisable.

Several studies [14–16] demonstrated the application of the SIMUL8 simulation environment for computer modelling. SIMUL8 is a software package designed for simulating systems involving discrete entities and discrete time processing based on process scheme. An event-based simulation model was created to assess the current utilisation of urban railway lines and explore possibilities for enhancing their capacity for freight services by analysing different scenarios with timetable design.

Paper by Wojnar, Irlik [18] discusses 25 premises assumed for a multi-criteria train movement model based on the trackside signalling equipment, which provided grounds for the development of simulation software in the Matlab&Simulink environment. The said simulation software was designed to assess the impact of the train control system solution in use on railway line capacity considering signalling principles used in Poland. In yet another paper [19], Folęga, Irlik have presented an example where the simulation software in question was used to establish the train departure delay time for known parameters of the rolling stock (e.g. movement characteristics) and the infrastructure, aimed at avoiding unnecessary braking and acceleration of trains running in succession. The authors' original train movement model, described in detail in their own paper [18], has been extended to account for the way in which trains move when they are ETCS-controlled by taking the braking characteristics defined in the relevant ETCS standard into consideration. The said simulation software enables extensive parameterisation of both the trains used for simulation purposes and the infrastructure, including the train control system. The available off-the-shelf simulation tools, suitable for railway capacity studies, use a train movement model based on traction characteristics. This opens up a possibility that there may be differences between the simulated train movement model and the manner in which trains are actually driven. Research [20] indicates that real-life train driving styles can influence the results of capacity assessment. Therefore, in consideration of the aforementioned, it has been suggested that for the purpose of modelling train movements, authentic characteristics of acceleration and braking should be employed. These characteristics can be derived from data collected during genuine commercial operations. This approach enables the study to emancipate itself from data particular to individual traction vehicles, while also accommodating the genuine train driving styles.

## 3. INFLUENCE OF SIGNALLING SYSTEM ON CAPACITY

Preliminary proprietary investigations [21] elucidate distinctions between train driver based on lineside signalling and the computationally determined safe braking curves prescribed by the ETCS system. Notably, it is ascertained that at a velocity of 160 km/h, the ETCS mandates the train driver to initiate braking pre-emptively, preceding the terminus of the authorised travel distance, specifically at a distance of 1725 m. This directive entails a lead of 424.68 metres over the extant maximum braking distance normatively adopted in Poland, quantified at 1300 metres for velocities of 160 km/h. This variance can be attributed to the incorporation of imprecision in odometric train localisation within the ETCS system [21].

The paper referenced as [22] presents the outcomes of an investigative study conducted within the context of Slovakian railways, comparing diverse implementations of signalling systems and their corresponding implications on capacity. The findings of this research demonstrate that the adoption of ETCS (European Train Control System) Levels 1 and 2 engenders a reduction in capacity when juxtaposed against the prevailing domestic signalling framework. However, the incorporation of ETCS Level 2, accompanied by the meticulous optimisation of section lengths, holds the potential to maintain the extant capacity level while concurrently elevating safety standards. Conclusively, the implementation of ETCS Level 3 exhibits the capability to substantially augment network capacity.

The protraction of braking duration engenders a corresponding elongation in the temporal occupation of a designated infrastructural segment (block interval), thereby consequentially extending the temporal interstice between successive train transits. Furthermore, the implementation of the ETCS system permits an increase in the maximum train speed for operations on the line, which, in turn, may potentially reduce the overall capacity. To achieve increase capacity the block length for train separation has to be adjusted for ETCS operation [8].

The outcomes derived from the study conducted on the Utrecht–Den Bosch corridor in the Netherlands, as expounded in reference [23], unveil that the deployment of ETCS Hybrid Level 3, in conjunction with the constricted reduction of block lengths to 100 meters at critical junctures along the corridor, engenders a noteworthy reduction in infrastructure occupation, attenuating to 66.7%. This stands in juxtaposition to the 84% occupancy observed under the auspices of the indigenous signalling system. This resultant decline consequently engenders the formulation of a practicable, robust and stable timetable paradigm, thereby ensuring that the degree of infrastructure occupation remains confined below the 75% threshold as advocated by UIC [10]

The railway system is distinguished by varying signalling principles implemented on a country-by-country basis, alongside differing operational regulations. Consequently, reutilising studies conducted within dissimilar signalling environments is deemed inefficient. This is also influenced by the signalling system and equipment, coupled with an advanced Traffic Management System incorporating conflict detection and resolution mechanisms, along with a Driver Advisory System or Automatic Train Operation [24].

The authors' original simulation software was used to study diverse configurations of the train control system in terms of their effect on line capacity. The studies comprised configuration tests of the railway traffic control system, accounting for the signalling principles employed in Poland and introducing an augmented division of traditional blocks through the incorporation of virtual blocks. These virtual blocks were devised based on specific logical states contingent upon train-reported positioning and train integrity information.

## 4. RAILWAY LINE CAPACITY SIMULATION TESTS

The section between the Psary and Góra Wlodowska stations, situated on railway line 4 of the Central Railway Line (Centralna Magistrala Kolejowa, CMK), which connects Warsaw with Katowice in the southern part of Poland, has been chosen as the study's sample area. Currently equipped with ETCS Level 1, this section is undergoing an upgrade to ETCS Level 2 with lineside signalling. Covering a distance of 35 km, it is divided into 21 block sections. After the modernisation, the maximum speed under ETCS Level 2 will be 250 km/h. The majority of trains operating on this line are equipped with on-board ETCS. Consequently, this infrastructure could be utilised as a reference for demonstrating capacity studies for ETCS Hybrid Level 3. The actual infrastructure of track 1 running from Psary towards the station of Góra Włodowska was mapped in the simulation software, and spacing of its elements as well as the length of its blocks have been summarised in *Table 1*.

*Table 1 – Spacing of the infrastructure elements within the Psary–Góra Włodowska route – track 1*

| Track circuit designation | Start optical signal designation | Start optical signal position [km] | End optical signal designation | End optical signal position [km] | Block length [m] |
|---|---|---|---|---|---|
| it1713 | N | 0.000 | 1727 | 2.411 | 2,411 |
| it1727 | 1727 | 2.411 | 1743 | 3.871 | 1,460 |
| it1743 | 1743 | 3.871 | 1759 | 5.568 | 1,697 |
| it1759 | 1759 | 5.568 | 1773 | 7.043 | 1,475 |
| it1773 | 1773 | 7.043 | 1789 | 8.592 | 1,549 |
| it1789 | 1789 | 8.592 | 1807 | 10.412 | 1,820 |
| it1807 | 1807 | 10.412 | 1827 | 12.699 | 2,287 |
| it1827 | 1827 | 12.699 | 1841 | 14.120 | 1,421 |
| it1841 | 1841 | 14.120 | 1859 | 15.765 | 1,645 |
| it1859 | 1859 | 15.765 | 1881 | 18.044 | 2,279 |
| it1881 | 1881 | 18.044 | 1897 | 19.693 | 1,649 |
| it1897 | 1897 | 19.693 | 1917 | 21.716 | 2,023 |
| it1917 | 1917 | 21.716 | 1935 | 23.512 | 1,796 |
| it1935 | 1935 | 23.512 | 1951 | 24.967 | 1,455 |
| it1951 | 1951 | 24.967 | 1967 | 26.573 | 1,606 |
| it1967 | 1967 | 26.573 | 1981 | 28.033 | 1,460 |
| it1981 | 1981 | 28.033 | 1995 | 29.401 | 1,368 |
| it1995 | 1995 | 29.401 | 2009 | 30.805 | 1,404 |
| it2009 | 2009 | 30.805 | 2023 | 32.206 | 1,401 |
| it2023 | 2023 | 32.206 | 2035 | 33.518 | 1,312 |
| it2035 | 2035 | 33.518 | B | 34.877 | 1,359 |

*Source: In-house study*

Trains moving within the route in question run with a maximum speed of 160 and 120 km/h, for passenger and freight trains respectively. A four-aspect block signalling system is installed on the route, however, as shown in *Table 1*, the block lengths were set as for a three-aspect system, i.e. the block length is longer than the assumed braking distance (1,300 metres for a running speed of 160 km/h, as per [25]).

An additional division into three virtual block sections of fixed length was applied to the existing route division into block sections (as shown in *Table 1*). Two virtual signals were added between the actual signals. The coordinates of the signals and detectors in the route configuration subject to analysis, represented as a matrix in the section model, have been provided in *Table 2*.

*Table 2 – Coordinates of signals defined automatically in model environment as per the route configuration analysed*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Columns 1 through 11 | | | | | | | | | | |
| **0.0000** | 0.0804 | 0.1607 | **0.2411** | 0.2898 | 0.3384 | **0.3871** | 0.4437 | 0.5002 | **0.5568** | 0.6060 |
| Columns 12 through 22 | | | | | | | | | | |
| 0.6551 | **0.7043** | 0.7559 | 0.8076 | **0.8592** | 0.9199 | 0.9805 | **1.0412** | 1.1174 | 1.1937 | **1.2699** |
| Columns 23 through 33 | | | | | | | | | | |
| 1.3173 | 1.3646 | **1.4120** | 1.4668 | 1.5217 | **1.5765** | 1.6525 | 1.7284 | **1.8044** | 1.8594 | 1.9143 |
| Columns 34 through 44 | | | | | | | | | | |
| **1.9693** | 2.0367 | 2.1042 | **2.1716** | 2.2315 | 2.2913 | **2.3512** | 2.3997 | 2.4482 | **2.4967** | 2.5502 |
| Columns 45 through 55 | | | | | | | | | | |
| 2.6038 | **2.6573** | 2.7060 | 2.7546 | **2.8033** | 2.8489 | 2.8945 | **2.9401** | 2.9869 | 3.0337 | **3.0805** |
| Columns 56 through 64 | | | | | | | | | | |
| 3.1272 | 3.1739 | **3.2206** | 3.2643 | 3.3081 | **3.3518** | 3.3971 | 3.4424 | **3.4877** | | |

*Note: Position of signals = 1.0e+04, optical signals from Table 1 are marked in bold*

The tests conducted under the studies were based on an assumption that train P moved according to the profile depicted in *Figure 1*. This profile consists of the acceleration characteristics established by way of the measurements performed during the commercial runs as well as the braking characteristics obtained in the simulations.

Corresponding to the ETCS braking characteristics [21]. *Figure 2* shows sample braking characteristics according to the ETCS standard [21] generated in the simulation software.

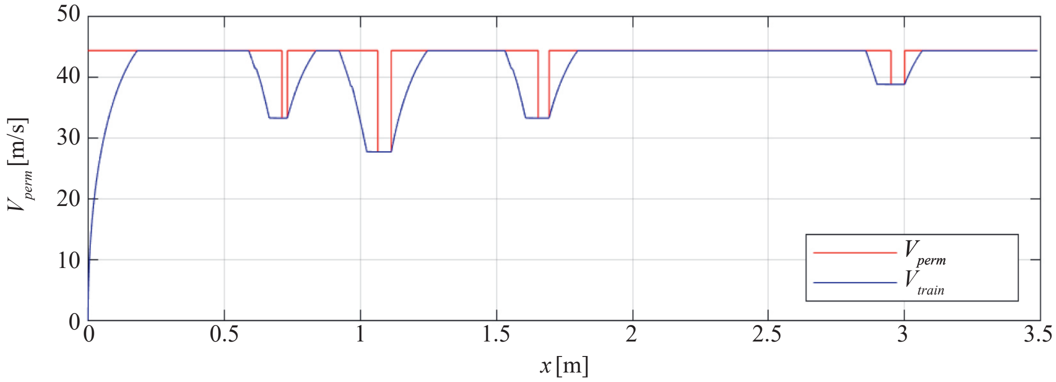

*Figure 1 – Maximum speed profile for the section with train movement characteristic taking into account the ETCS braking curves and the real acceleration characteristics established by actual measurements (Source: Based on measurement during commercial service EMU train)*

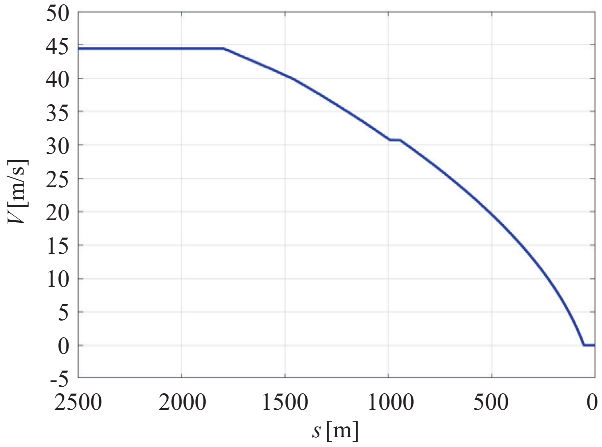

*Figure 2 – Example of braking characteristic corresponding to the ETCS braking model (Source: Based on [21])*

Another assumption made for the purposes of the studies was that the subsequent train P+1 also moved between specific route coordinates with speeds corresponding to the characteristics provided in *Figure 3*. The subsequent train (P+1) departed at second 82, i.e. when the exit signal (Sem. 1) showed the proceed aspect, which happened after 81.5 seconds of the simulation commencement.

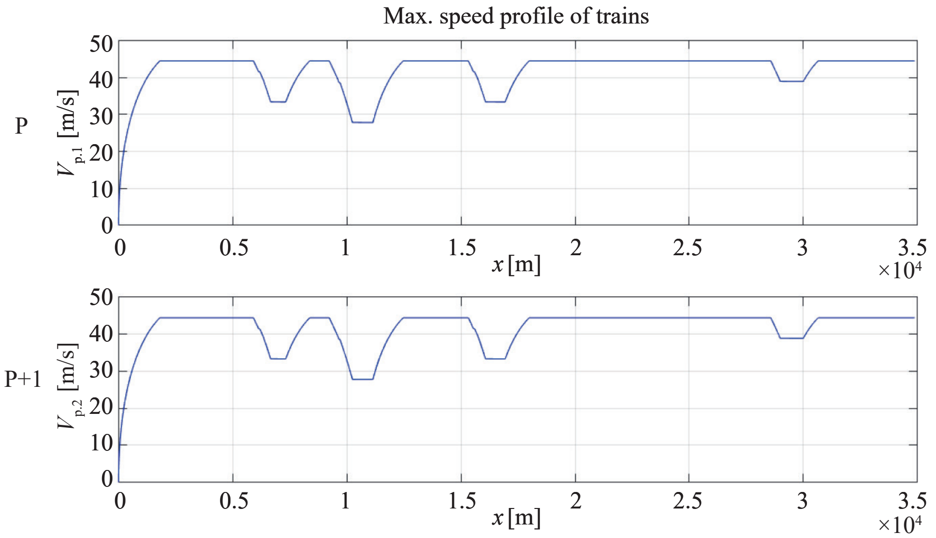

*Figure 3 – Movement characteristics of the train*

*Figure 4b* illustrates the increase in the running speed of train P+1 starting from 82 seconds, while *Figure 4* shows the distance covered by the end of train P and the front of train P+1. *Figure 4c*, on the other hand, illustrates the increase in the braking distance of train P+1 relative to the time which has elapsed since the beginning of the movement of train P and the running speed of train P+1. *Figure 4d* implies that, after approx. 155.7 seconds, the “stop” signal changed from “1” to “0”, meaning the obligation of train P+1 to initiate

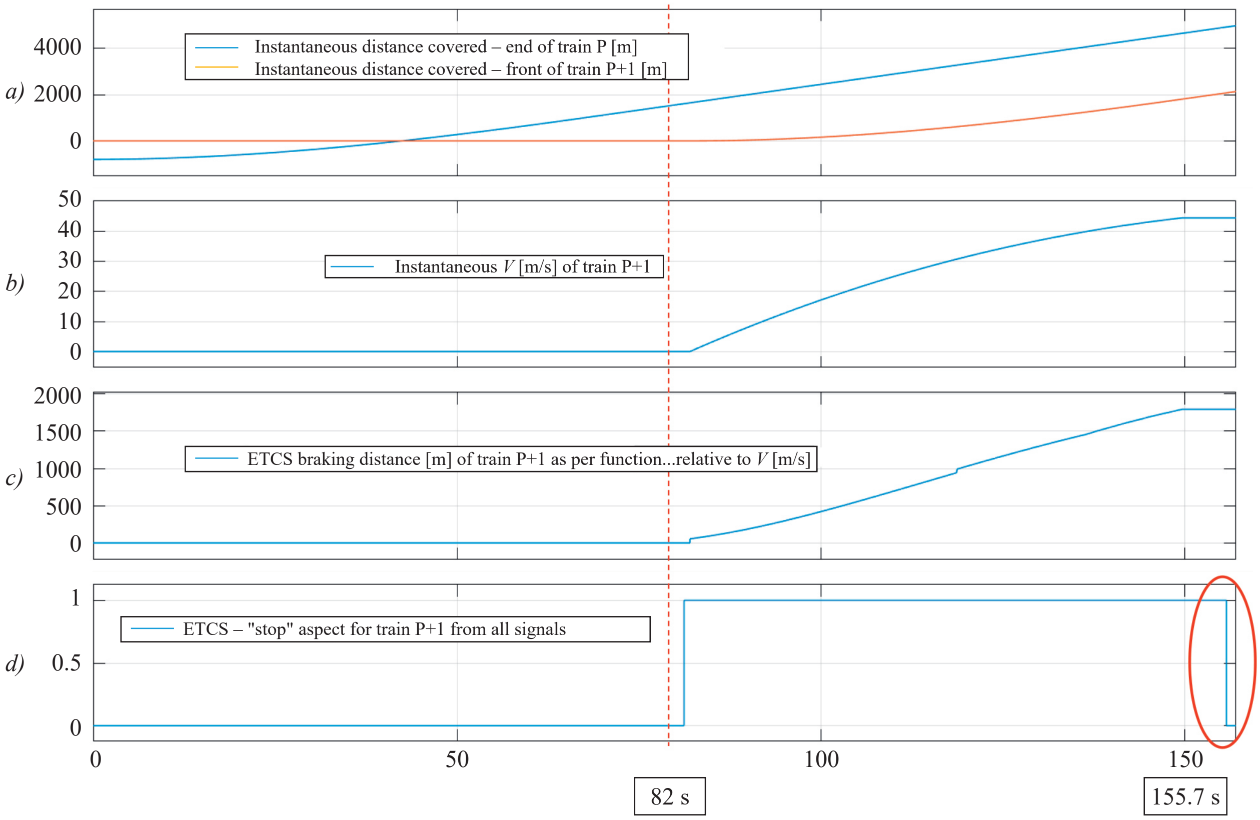

*Figure 4 – a) Instantaneous distance travelled by the trains; b) Speed profile of train P+1; c) Braking distance of train P+1; d) Behaviour of the “stop” signal for train P+1*

braking. At approximately 155.7 seconds, the coordinate of the end of train P is 4,437 m, which corresponds to the block covered by virtual signal no. 8. At the same instant, the point at which train P+1 has stopped is 3,871 m, corresponding to the coordinate of signal no. 7.

*Figure 5a* shows the instantaneous braking distance according to the ETCS characteristics for train P+1. At the analysed time instant (155.7 seconds), the braking distance of train P+1 was 1,796 m. At the same instant, the front of train P+1 reached the coordinate corresponding to the braking distance (1,796 metres to the coordinate of the signal setting the end of the authority to proceed, its on-route coordinate being 3,871 m). This means that the distance between the train front and the braking start point was 0 metres (*Figure 5b* – marked by red circle), which is why train P+1 had to initiate braking. This, in turn, caused the value of the "stop" signal to change from "1" to "0" at the given time instant (*Figure 4d*). Had train P+1 not started braking at this instant, the distance between the front of this train and the braking start point would have started taking negative values (as illustrated in *Figure 5b* at the encircled point). The relationship between the distance to the braking start point, the braking distance and the distance to the stopping point has been illustrated in *Figure 6*.

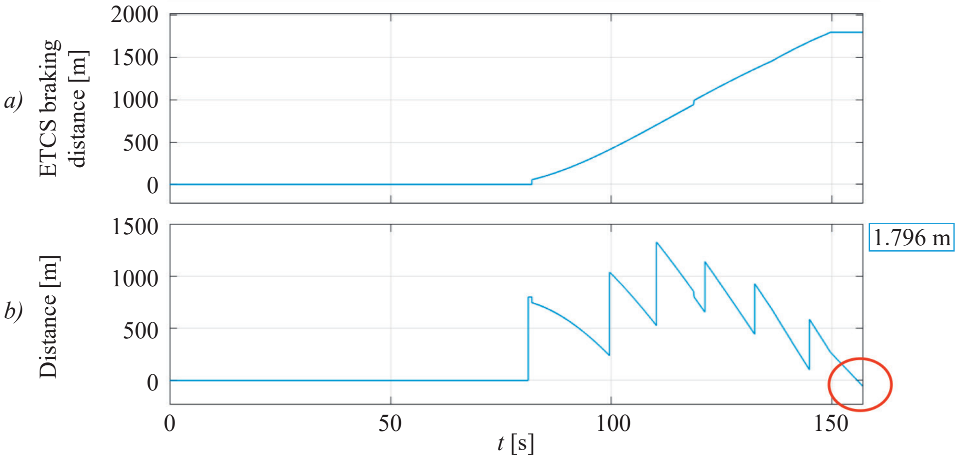

*Figure 5 – a) Projected braking distance of train P+1; b) Distance to the braking start point of train P+1*

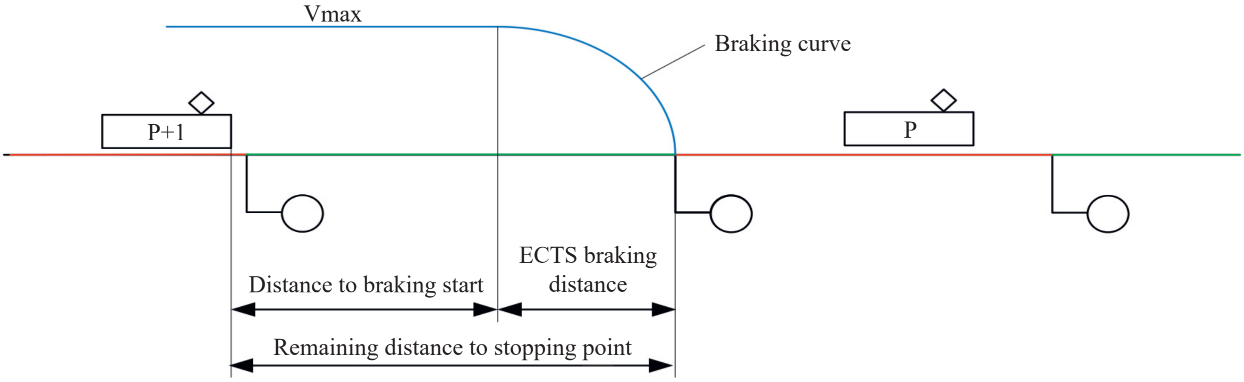

*Figure 6 – Illustration of terms used on waveforms from the simulation environment*

In another simulation, train P+1 was allowed to depart to the route at the instant corresponding to the simulated 115.5 s (*Figure 7b*). In this case, the "stop" signal reached the value of "0" at the instant of approx. 346.5 seconds (*Figure 7b*, red circle). At the same instant of time, the value of the distance between the front of this train and the braking start point was also 0 metres (*Figure 8b and 8c*, red circle). To provide a broader perspective of the results thus obtained, the graphs below also illustrate the changes in the distance covered by trains P and P+1 (*Figure 7a*), changes in the ETCS braking distance of train P+1 (*Figure 8a*).

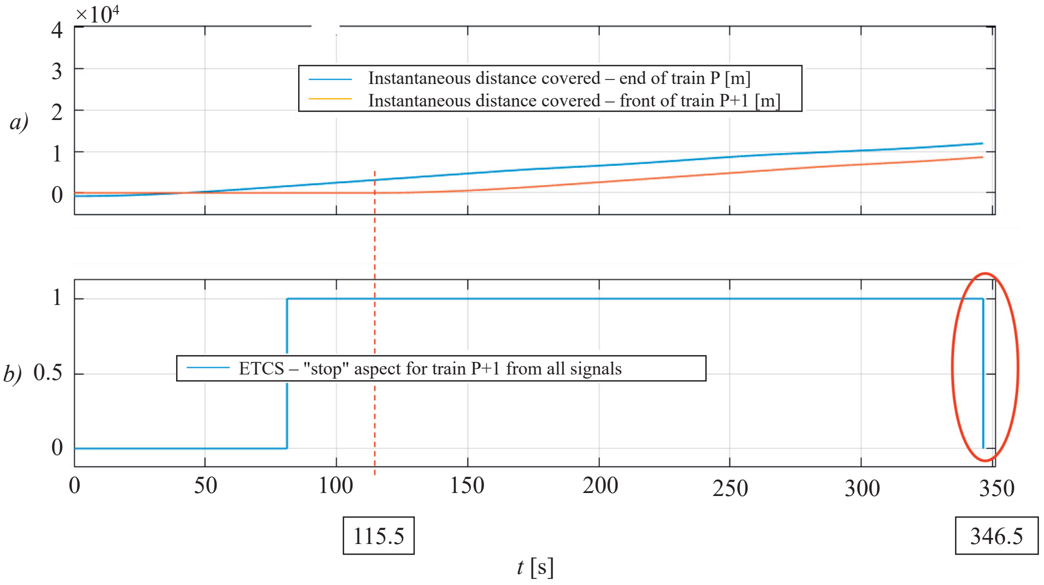

*Figure 7 – a) Distance travelled by the trains; b) Behaviour of the "stop" signal for train P+1*

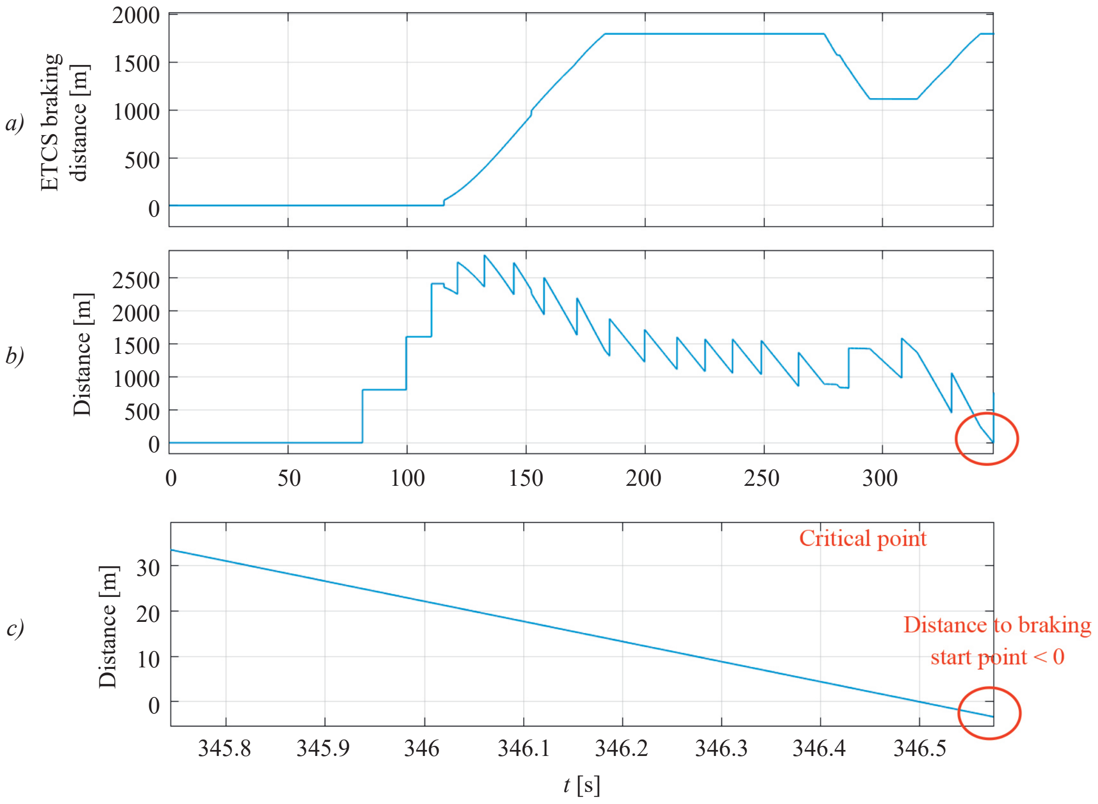

*Figure 8 – a) Projected braking distance of train P+1; b) Distance to the braking start point of train P+1; c) Zoomed-in graph showing part of figure 9c with critical point*

It was established that, where train P+1 started to move at the instant corresponding to second 115.6 in the simulation (i.e. 74.1 seconds after the train was given the authority to depart), the "stop" signal did not reach the value of "0" during the movement of train P+1 along the entire route (*Figure 9d*). This means that there was no need for train P+1 to initiate braking as a consequence of its interaction with train P. To enable a more detailed analysis of the results thus obtained, the graphs below also illustrate the changes in the distance covered by trains P and P+1 (*Figure 9a*), changes in the speed of train P+1 (*Figure 9b*), and the instantaneous value of the braking distance of train P+1 (*Figure 9c*).

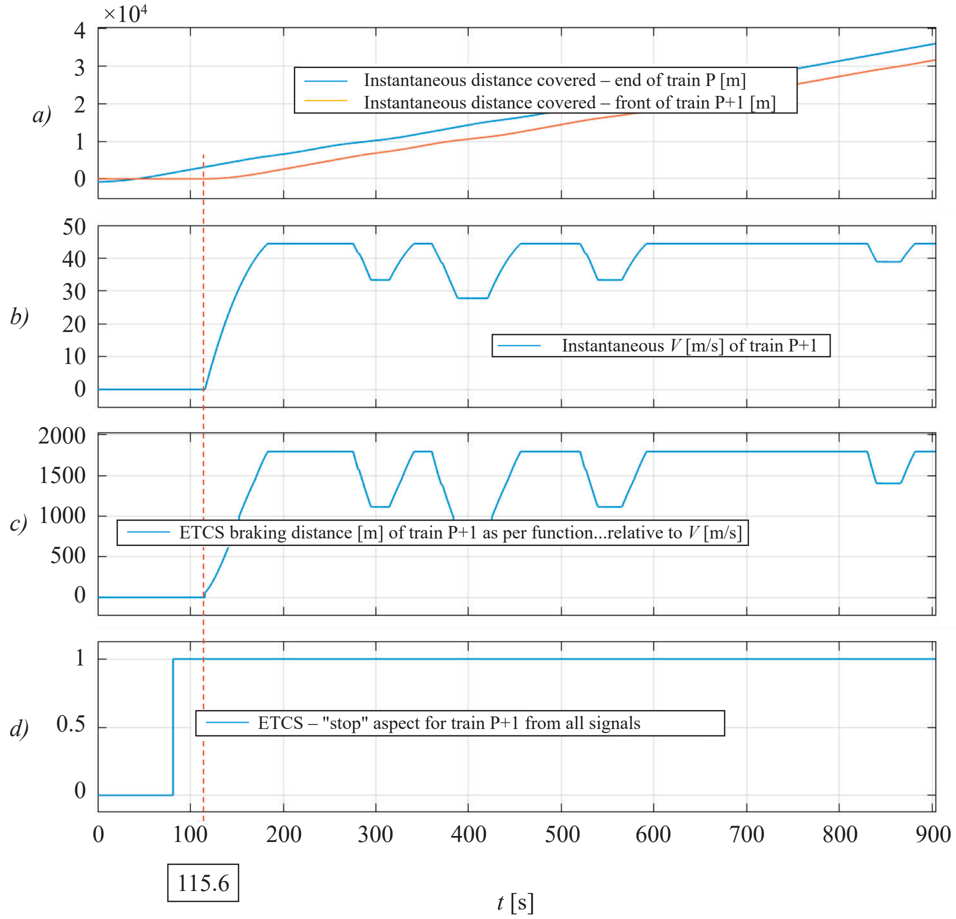

*Figure 9 – a) Distance travelled by the trains; b) Speed graph of train P+1; c) Braking distance of train P+1 as per ETCS; d) Behaviour of the "stop" signal for train P+1*

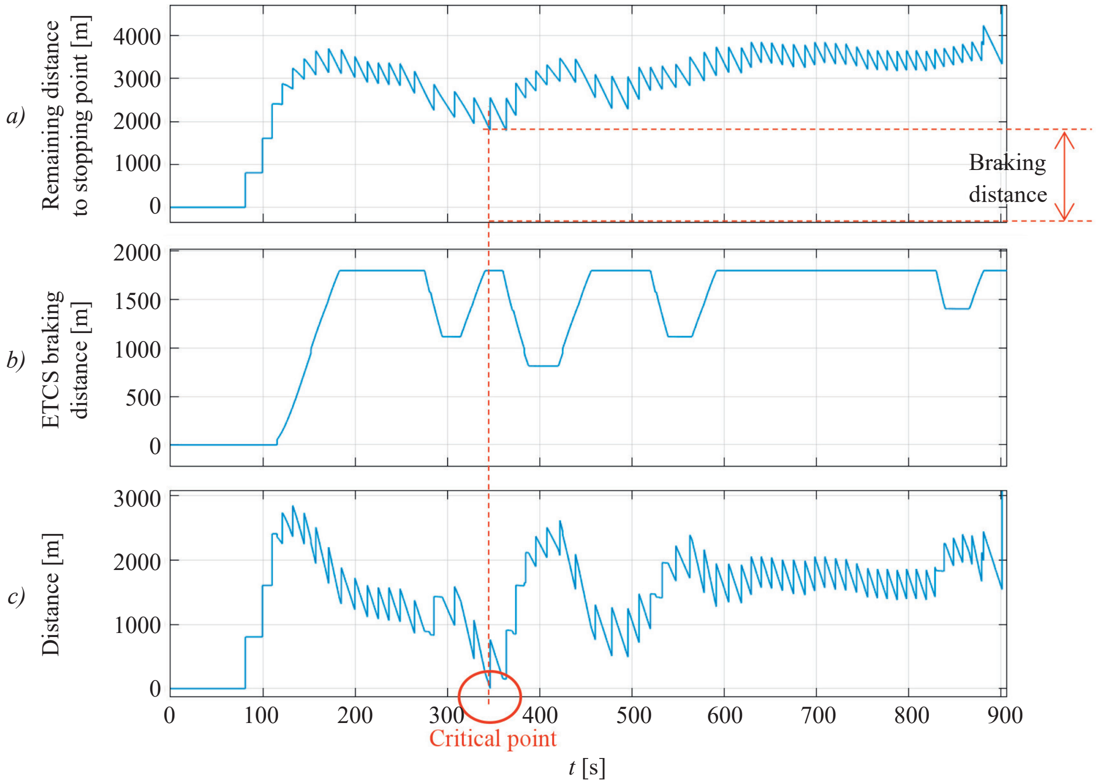

*Figure 10 – a) Distance to the stopping point of train P+1; b) Projected s braking distance of train P+1; c) Distance to the braking start point of train P+1*

Fig. 10c shows that the value of the distance between the front of train P+1 and the start of the braking distance was approaching "0", but did not reach this value. This location can be called the critical point for a given configuration of characteristics of the movements of trains P and P+1 for a given route. The coordinate of this point may vary depending on the speed characteristics of two consecutive trains, one running behind the other. It should also be noted that, where this is the case, the ETCS will send audible and visual warnings to the driver. *Figure 10a* shows the instantaneous distance to the stopping point of train P+1, while *Figure 10b* – the projected instantaneous braking distance of train P+1.

The departure of train P+1 115.6 s after the moment when the preceding train P ran past the exit signal (Sem. 1), i.e. 74.1 seconds after it received the authority to depart to the route (115.6 seconds – 81.5 seconds), caused that train P+1 did not need to brake and accelerate, except where there was a regulatory speed limit on the route analysed. This value can be treat as a minimum headway time.

Assuming the given traffic structure and considering the assumptions previously adopted, the number of trains which could pass through the route subject to analysis is $N_t$=3600/115.6=31.1 s. It is the maximum number of trains with the assumed movement characteristics which can be processed over one hour on the given route. The time it took a train to traverse this route was 880.98 seconds.

## 5. RESULTS

*Figure 11* shows results of the minimum headway time and the maximum number of trains of a given type and with known acceleration and braking characteristics which can traverse the analysed route over one hour with reference to the results of the simulation tests, one can conclude that introducing an additional block section division to the analysed route using virtual blocks exerts a considerable effect on the line capacity:

- in the absence of additional virtual signals, the maximum railway line capacity is $N_t$=21.8 train/h;
- with one additional virtual signal (actual block divided into two additional virtual blocks), the maximum railway line capacity is $N_t$=27.1 train/h, which represents a relative increase of 24%;
- with two additional virtual signals (actual block divided into three additional virtual blocks), the maximum railway line capacity is $N_t$=31.1 train/h, which represents a relative increase of 43%.

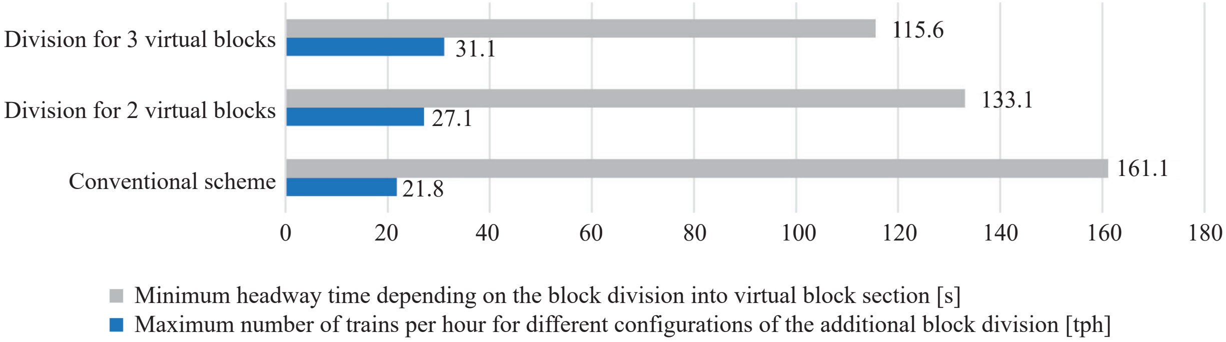

*Figure 11 – Maximum number of trains per hour for different configurations of the additional block division*

The outcomes of research with the relative change in the maximum train frequency per hour between the implementation of ETCS Level 2 on a conventional scheme and the application of ETCS Hybrid Level 3 featuring the incorporation of three virtual blocks, align with the findings detailed in reference [26]. This correspondence extends to the context of capacity increase for the main lines equipped with ETCS Level 2 service braking compared to ETCS Level 3, as exemplified in *Figure 12*. The application of ETCS Level 3 can be likened to the utilisation of appropriately sized virtual sub-sections in Hybrid Level 3 solution, where the length of these sections corresponds to the train's position reporting interval.

## 6. CONCLUSIONS

The paper provides a results on the simulation-based studies of railway capacity using a train movement model based on the ETCS-compliant cab signalling system. In the context of modelling physical phenomena like train dynamics, proprietary models facilitate the incorporation of acceleration and deceleration profiles of train movements taken from measurements. This capability presents a clear advantage over commercially available software applications commonly employed for capacity assessment. Furthermore, the model

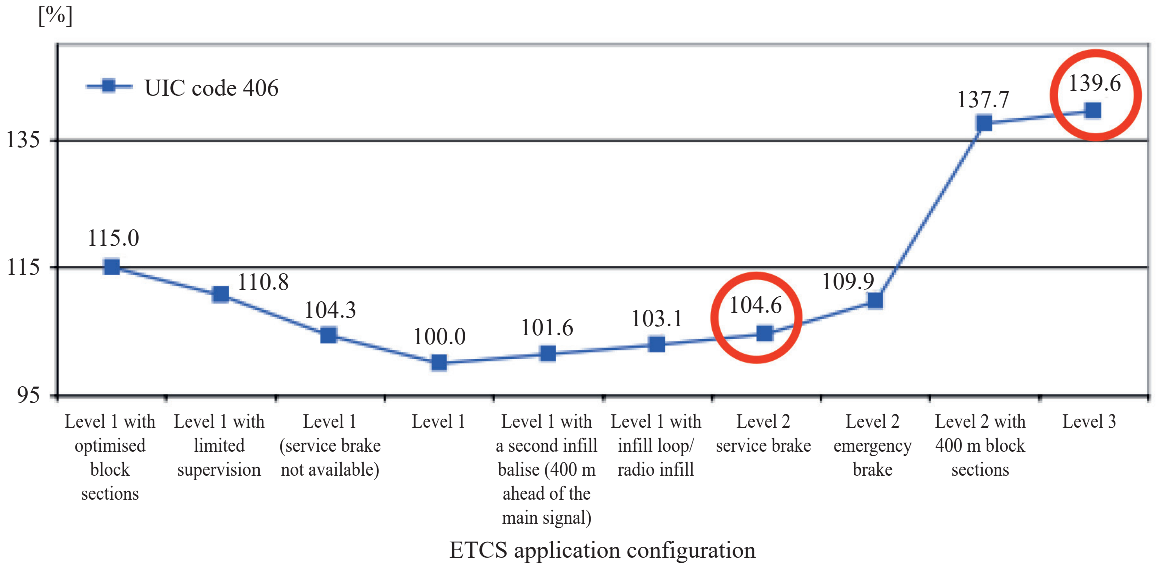

*Figure 12 – Increase in capacity for the conventional main line [25]*

accommodates the integration of braking characteristics consistent with the specifications outlined in the ETCS system standard. The relevant tests were conducted using a model of the Psary–Góra Włodowska route on railway line no. 4 (Central Railway Line). The obtained results are aligned with other studies prepared by UIC [26] and other research executed considering local signalling principles in other countries [6, 22, 23].

The above study results have not only confirmed the validity of the methodology proposed for railway line capacity testing based on the aforementioned simulation method, but have also provided rationale for the application of an additional block division based on virtual block sections for increase capacity. Making use of the results thus obtained, one can also establish the critical point, as it is conventionally referred to, i.e. the place where it may be necessary for a train to initiate braking upon reaching the coordinate of the braking start point which does not result from any regular or emergency warnings. It should be noted that the obtained results concerning the maximum number of trains represent only certain initial data for further analyses, including practical capacity, traction power efficiency and others. It is also important to emphasise that the railway track's capacity is dependent on the capacity of the stations at its ends. Nevertheless, the obtained results allow for the determination of the actual, minimum time interval between dispatching successive trains (i.e. the traffic chart period) while taking into account the actual train movement characteristics. They also serve as confirmation of the applicability of the presented method for assessing design solutions in railway traffic control and management systems.

While developing the train motion models under consideration, efforts were made to anticipate as many scenarios as possible that may occur during train operations. For this reason, in the simulation software, data matrices were created to mathematically describe these phenomena. Although not all these phenomena were utilised in the presented research, this data enables further development of the simulation software.

## 6. FUTURE WORK

In the context of ongoing research efforts, the development of simulation software is envisaged to facilitate the examination of solutions integrated into railway traffic control systems as a result of current market trends and legislation. These solutions encompass, among others, the capability to investigate algorithms within Train Management Systems (TMS) aimed at detecting and resolving traffic conflicts, as well as the implementation of Automatic Train Operation (ATO) at the GoA2 automation level to enhance railway line capacity. Additionally, with regard to support for the simulation environment, there is an anticipated development of an algorithm to automate the input of real data related to train motion characteristics obtained from on-board recorders into the developed simulation software. These endeavours align with the concept of the ETCS digital twin, which is also within the research interests of the authors.

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# Railway line capacity relative to additional block division

## Streszczenie

Artykuł omawia wyniki badań dotyczących zdolności przepustowej linii kolejowej w odniesieniu do zastosowania dodatkowego podziału odstępów za pomocą wirtualnych bloków w procesie pozycjonowania pociągu, raportującegoswoje położenie oraz integralność składu pociągu. Badania przeprowadzono przy użyciu autorskiego oprogramowania symulacyjnego umożliwiającego parametryzację infrastruktury, w tym konfigurację systemu sterowania pociągami oraz zasad sygnalizacji, w tym uwzględniając rzeczywiste charakterystyki ruchu pociągów na podstawie danych uzyskanych z pomiarów w terenie.

## Słowa kluczowe

przepustowość linii kolejowej; ETCS; badania symulacyjne; MATLAB, Simulink.