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Piotr FOLĘGA
Silesian University of Technology, Faculty of Transport and Aviation Engineering
Krasińskiego 8, Katowice, 40-019, Poland
Maciej IRLIK*
*(Alstom) Bombardier Transportation (ZWUS) Polska Sp. z o.o.
Modelarska 12, Katowice, 40-142, Poland
**Corresponding author*. E-mail: maciej.irlik@alstomgroup.com

EFFECT OF TRAIN POSITION REPORTING ON RAILWAY LINE CAPACITY

Summary. Over the recent years, an increase in the demand for passenger and freight rail transport services has been observed. This is mainly owing to the policy objectives related to the use eco-friendly means of transport and the investment causing the quality of rail services to grow. Along with the growing demand for rail transport, a problem of railway capacity utilisation has emerged. Although the implementation of the new Automatic Train Protection (ATP) system increases the safety level, but under some scenarios, it may decrease the headways between trains. At the same time, the ATP systems enables train positioning based on odometry calculation and reporting it to the trackside system. This paper proposes a solution that involves application of virtual block sections which use the train position reporting feature of the ATP system for the determination of non-occupancy. Virtual blocks can successfully reduce headways in railway lines without increasing the number of trackside signalling devices. The capacity assessment proposed under the study was performed to calculate the average headway depending on the signalling system configuration.

1. INTRODUCTION

Insufficient railway line capacity translates into the necessity of either limiting the rail transport offering or re-routing trains on alternative lines, which may cause the rail transport to cease being competitive compared with road transport. This body of problems was addressed in a paper [1] whose authors proposed a process of decision making with regard to alternative train line routing or travel time extending. As implied by the calculated cost-to-time loss ratio, on insufficient infrastructure capacity, the cost of setting an alternative train route can be up to ca. 50% higher than that related to the shortest route, which corresponds to the cost of two additional hours of extended time of running on the shortest route [1].

From a traditional perspective, the transfer of information concerning the permissible main set route and that required for headway control by ensuring safe distance between trains is managed by means of the trackside signalling equipment. In the railway network operated by PKP PLK S.A., following an upgrade or installation of new railway traffic control devices, the trackside signalling equipment used comprises multi-aspect light signals that provide information about the permissible speed for running in two (three-aspect signalling) or three (four-aspect signalling) successive blocks on the route.

According to the National Plan for Implementation of the Technical Specification for Interoperability relating to the ‘control-command and signalling’ subsystem [2], the European Train

Control System (ETCS) is currently being deployed in the Polish railway network as a replacement for the legacy system used in Poland - Automatic Train Braking System (SHP). The ETCS is intended to ensure interoperability, increase the level of safety by preventing the consequences of human errors, and provide new functionality related to the possibility of traffic operations performed at speeds above 160 km/h [2]. In contrast to the Automatic Train Braking System (SHP), the on-board ATP (Automatic Train Protection) computer of the ETCS performs continuous supervision of the permissible train running speed depending on the train's position. This supervision is based on movement authorization, on the infrastructure-specific data acquired from the trackside equipment, as well as on the given train's braking system specifications, among other parameters. With reference to the data being acquired, the system calculates a dynamic permissible speed profile (referred to as a braking curve) according to which it performs the train movement supervision. A computational braking curve does not take into account the traditional headway division according to standardized braking distances, and so it can be different for each train. The ETCS implementation (on application Level 2 and higher) also entails introducing continuous track-to-train data transmission for updating movement authorizations and sending them to trains, but also for purposes of cyclic train position reporting to trackside equipment against fixed location markers referred to as balises. Each position report provides various information, including the estimated position of the train front, and specifies the data inaccuracy [3]. This information can be used in the train traffic management process.

Following safety and investment costs, the railway line capacity criterion is one of the aspects taken into consideration when designing a railway traffic control system. One of the ways to increase this capacity when designing the railway traffic control system is, for instance, increasing the number of aspects of the block system, thus making it necessary to add new non-occupancy control sections. However, such solutions generate additional investment and maintenance costs for the railway line.

The goal of this paper is to discuss the effect of implementation of the ETCS-type ATP system on braking distances and to present the method for an additional division of blocks (without the need for physical extension) using the train position reporting function for the sake of non-occupancy determination. What the paper also provides is a preliminary assessment of the solution proposed in terms of its effect on the capacity parameters.

2. THE STATE OF THE PROBLEM

2.1. Braking curve supervision in the ATP system

When in movement, with reference to the fixed blocks and using the trackside signalling equipment, trains are operated on the basis of the indications of trackside signals, providing information about the movement path past the given signal and, depending on the set number of aspects, information on the status of the subsequent or the next two blocks. As argued in a study [4], braking distances are determined by the lengths of fixed blocks. This is not the case of the braking process when the train movement is supervised by the ATP system, where the on-board systems use the control panel to inform the driver of the need to apply the brakes. The position indicated by the ATP system not always corresponds to the physical location of trackside signals or to the block division, but instead it depends on the braking characteristics of the given train, as calculated by the system.

The task of the ETCS-type ATP system is to supervise the train position and running speed to check whether these parameters are within acceptable limits at any given time. If this is not the case, the system intervenes by sending a command to the traction vehicle's braking system via its interface to apply service braking or emergency braking. For this purpose, the ETCS system must use the relevant train braking behavior parameters to predict the actual train braking behavior within the given infrastructure section. The braking curve models applied in the ETCS are based on a mathematical and physical description of the vehicle braking behavior [5]. These models rely, among other parameters, on data concerning the rail vehicles forming the train set, e.g., on the dependences of train deceleration, speed and braking system's inertia time, traction parameters, and train length.

Furthermore, they are also based on data concerning the movement authorization, such as the length resulting from the pre-set blocks and characteristics (longitudinal gradient and speed profiles) assigned to the train. The prediction of the train braking behavior based on characteristic $f(s)=v$ is referred to as the braking curve [5], where s is the distance and v designates the speed. Depending on the train set type and the available data, what one uses to calculate the braking curves in the ETCS is the γ model, which is based on nominal deceleration values for different intervals of speed *A_brake(v)* [m/s^2], known for a specific train set (typically used for multiple units), as well as on correction factors determining the difference between the nominal deceleration value and the guaranteed value for braking on dry and wet rails. With regard to train sets that can be freely combined (typically wagon train sets), one applies the λ model, which, with reference to the percentage value of actual braking mass P_r. determined for the given train set, the train length, and the braking system type (e.g. fast-acting or slow-acting brake), makes it possible to establish the *A_brake(v)* [m/s^2] characteristic based on conversion model [6].

The effect of the ETCS on traffic control has been described in a paper [7]. The authors of that publication have concluded that timetables are planned on the basis of nominal traffic conditions, while a safe ATP system should consider the most adverse conditions related to the availability of the train's braking force, the adhesion between the wheel and the rail, and the odometry measurement inaccuracy [3]. The phenomenon of deviations from the timetable when train movement is supervised by the ATP system may be particularly evident in cases of high heterogeneity of railway traffic and a large number of stops resulting from the authorizations being restricted by the ETCS, forcing trains to run according to a computational braking curve [8]. In some situations, the dynamic speed profile being calculated may be more restrictive than it would result from the driver's braking behavior, based on the indications of signals and on the conventional division into sections according to standardized braking distances.

An example of the difference between the driver's braking behavior and safe braking curve calculations performed by the ETCS has been illustrated using the characteristics shown in Fig. 1 as well as the braking distances collated in Table 1. The results provided in Fig. 1 and Table 1 refer to a type 104Ec series EP09 locomotive of the serial number 029. The *Emergency Brake Deceleration Curve* (*EBD), Emergency Brake Intervention supervision limit (EBI), Warning supervision limit (W)* and *Permitted speed supervision limit (P)* characteristics relate to the braking supervision by the ETCS, and they were calculated by a simulation method using the ERA tool (braking curve simulation tool), which calculates braking curves according to the ETCS model, as described in SUBSET-026 [6]. The parameters of the type 104Ec series EP09 locomotive, corresponding to the real ones, were applied along with the percentage value of the actual braking mass of $P_r=115\%$. The *EB 160 Driver* characteristic was read from the Hasler on-board data recording unit following field tests which consisted in emergency braking from a speed of 160 km/h to a stop without the ETCS enabled. Three braking tests were conducted, and their results have been averaged and provided as the *EB 160 Driver* characteristic in Fig. 1.

Table 1

Braking distances for a speed of 160 km/h determined by simulation methods for the ETCS and by field tests using a type 104Ec series EP09 locomotive

	Permitted (P)	*Warning (W)*	*EBI*	*EBD*	Average measured braking distance for 104Ec, EP09	Required braking distance acc. to [4]
Braking distance [m]	1724,68	1635,79	1401,51	1179,99	1115,08	1300

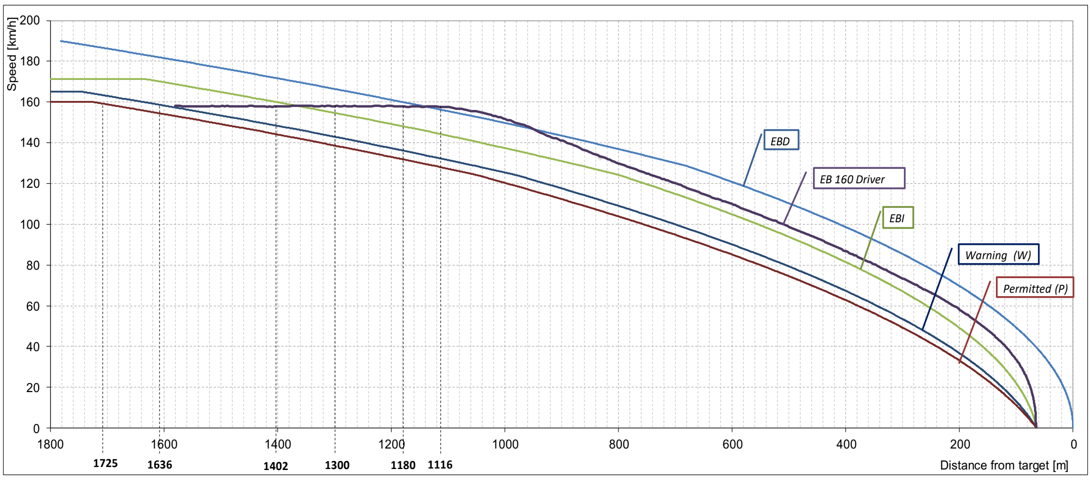


Fig. 1. Braking characteristics of a type 104Ec series EP09 vehicle (*EBD, EBI, Warning (W), Permitted (P)* characteristics calculated by simulation methods; *EB 160 Driver* characteristic determined by field tests).

As per [5], the *Permitted speed supervision limit (P)* curve defines the speed at which the driver should autonomously apply brakes in order to prevent them from being enabled automatically by the on-board ETCS devices. Based on the test results thus obtained, as provided in Fig. 1 and in Table 1, it was found that, at a speed of 160 km/h, the system prompts the driver to start braking the train at a distance of 1,725 m before the authorized end, i.e., 424.68 m earlier than it would result from the braking distance assumed in the relevant Polish regulations, i.e. 1,300 m for a speed of 160 km/h. Longer braking time translates into the time of occupancy of a given section of infrastructure (block), and consequently increases the headway time after which the next train can be operated by the same block. As the train timetable establishing the capacity utilisation is developed on the basis of traditional braking distances (i.e. the *normal scenario*, as it is referred to), the application of the ETCS may cause deviations from the timetable in certain cases. The foregoing is also relevant for designing the ETCS trackside equipment because of the need to take into account different train types with different braking parameters which may display braking characteristics that differ from one another according to the ETCS [9].

2.2. Railway traffic control system vs railway line capacity

According to the traditional traffic management approach based on trackside signalling equipment, the railway line capacity depends on the number of aspects of the signalling devices. In the Polish practice, three-aspect signalling equipment is typically installed near stations to provide information about the permissible running speed in two successive sections. However, routes equipped with multi-section (automatic) block signalling systems feature three- or four-aspect signalling devices providing information about status *m-1* (where *m* is the number of aspects of the signalling equipment) of the blocks past the given signal [10]. The block length, and consequently also the arrangement of trackside signals, determines the braking distance. According to the traditional approach, one applies standardized braking distances dependent on the speed (1,300 m, 1,000 m, 700 m, and 400 m). For three-aspect signalling, the block length cannot be smaller than the braking distance, whereas in the case of four-aspect signalling equipment, this length can be reduced to half the braking distance. The foregoing results from the fact that the higher the number of aspects of the signalling equipment, the higher the potential capacity. The problem of the effect of the railway traffic control system and of the number of its aspects on the capacity of a railway line has been extensively discussed in numerous publications, particularly in those that elaborate upon the effect of conventional trackside signalling equipment and the number of its aspects on the railway line capacity [11–14].

Zhao [16] has analyzed the effect of the number of trackside devices (signals, in this case) on the railway line capacity per a kilometre of railway line for different numbers of aspects of the signalling equipment and for a moving block system. Table 2 provides the results obtained from simulation calculations considering the operating principles of the UK's railway traffic control systems [16].

When conventional trackside signalling equipment is in use, although developing the block division and increasing the number of aspects of the signalling equipment improves the capacity, it also increases the number of trackside devices considerably. Where this is the case, the number of signals and the associated non-occupancy detection devices grows. However, signalling equipment of the number of aspects higher than four is not used in Poland.

Table 2

Minimum point headway time against signalling systems and number of signals
[study based on [16]]

	3 aspects	4 aspects	5 aspects	6 aspects	Moving block
Min. train headway time t_H [s]	295	272	265	261	252
No. of trackside signals per km of line	0,40	0,65	1,08	1,40	N/A

The advancement of the digital railway traffic control systems has made it possible for trains to use position reporting to determine the non-occupancy of track sections. Combined with near-instantaneous radio transmission of updated movement authorisation information, this provides a number of possibilities, including application of the solutions based on moving block sections extensively discussed in the literature [17-20]. The authors of paper [21] has presented a formal B model of representation additional virtual fix subsections in traffic control signalling system that could be used for finer location train on the line without needs of moving block section but capacity assessment study was not considered.

A moving block section ensures safe separation of consecutive trains while reducing the amount of trackside equipment by referring to position reporting by trains and by confirming train set continuity. Introducing solutions based on moving blocks into common use requires that safety is maintained and that various train operation aspects are taken into account, including the following: possibility of managing mainline operations in situations where individual system components are unavailable (e.g. transmission network, or trackside equipment due to failure, etc.); managing mainline operations of trains non-equipped with system devices, including e.g. maintenance trains; and managing shunting operations within station areas and moving trains after terminating communication sessions (referred to as *cold movement*).

The foregoing aspects represent the current challenges facing traffic management, e.g., on trunk routes. This is particularly relevant in migration periods, when not all trains moving in the network are equipped with the on-board ETCS equipment, and hence the necessity of mixed traffic to be taken into account. Consequently, one should consider solutions that, on the one hand, would make it possible not to increase or even to reduce the number of trackside devices, and on the contrary, to improve railway line capacity parameters using the ETCS position reporting feature.

3. VIRTUAL BLOCKS CONCEPT

The classical discrete breakdown into fixed block sections can be extended by dividing these sections into smaller ones. In order not to increase the number of trackside devices, it is proposed to divide them into virtual blocks (WOB) (Fig. 2b), which do not require non-occupancy confirmation systems and trackside signals to be physically installed on the location, but only trackside signs to point where the movement authorisation ends and indicate where the train is to be stopped if the subsequent block is occupied.

The set of *n* virtual blocks would comprise a fixed block section in the traditional approach, i.e. terminated by physical non-occupancy confirmation devices. The logical state of such a virtual block could be defined as a logical sum of the route or the fixed block of which the former would be a part, the physical state of non-occupancy of a fixed block, and the train location as derived from its reported position.

Such a solution could make it possible to decrease the distance between two consecutive trains in motion. The concept of virtual blocks (WOB) proposed by the authors has been graphically compared with a three-aspect signalling system in Fig. 2.

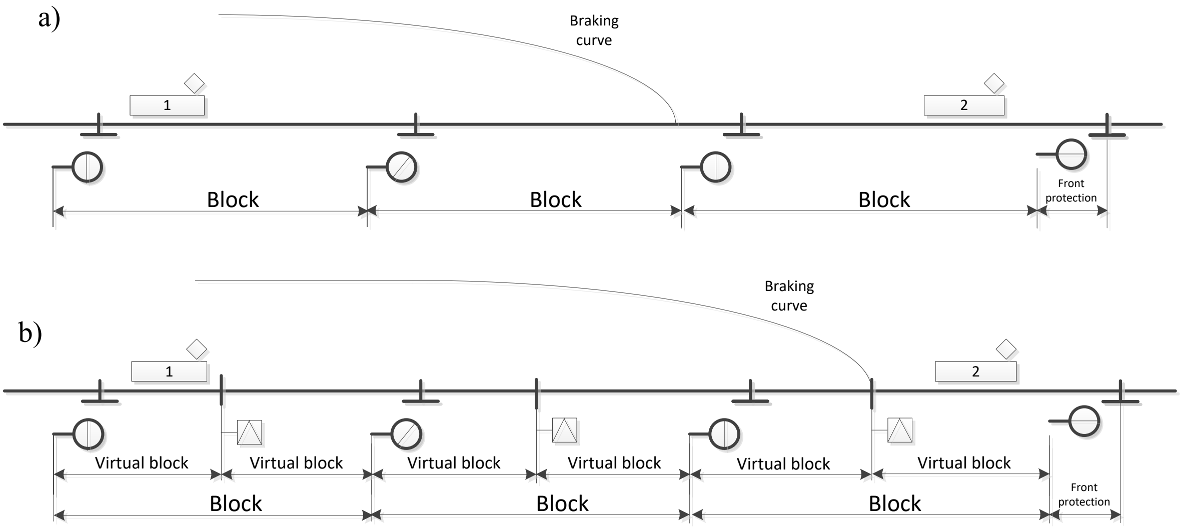


Fig. 2. Signalling system layout with a) fixed blocks and 3-aspect signalling, b) virtual blocks [authors' own study]

The concept illustrated in Fig. 2 is essentially similar to that which involves using 4-aspect light signalling; however, virtual blocks, as proposed, can be used in different configurations depending on the traffic type structure (i.e. the share of trains equipped and non-equipped with the on-board ETCS devices), as well as when taking the required capacity into account. It should be noted that such a division does not impose the use of additional trackside signals, and hence no need to consider local visibility conditions.

In the event of train-to-track communication failure, the state of individual virtual blocks cannot be confirmed. Where this is the case, it is proposed that, after the lapse of time τ, the virtual block in which the train has recently reported its position as well as the next one should assume a logical state that will prevent them from being assigned to the authorization granted to the subsequent train. This state should also propagate to the preceding virtual block in order to exclude any events related to potential train rolling down. Depending on whether or not the given section is within the same conventional block, a transition to the *blocked* state may take place upon detecting physical non-occupancy in the given block, or upon the lapse of the propagation time (Fig. 3).

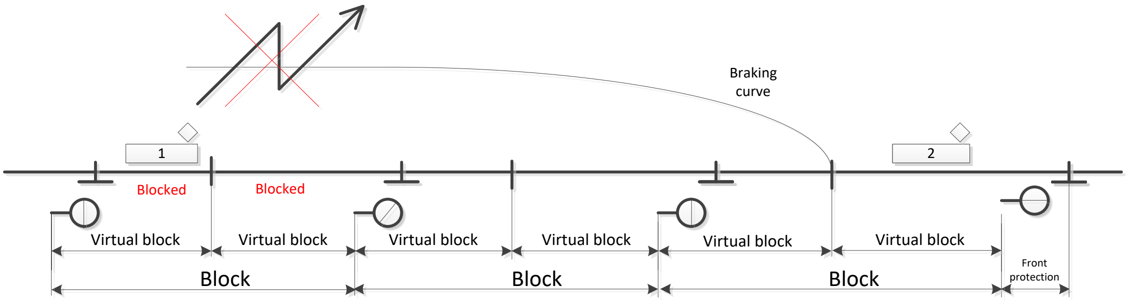


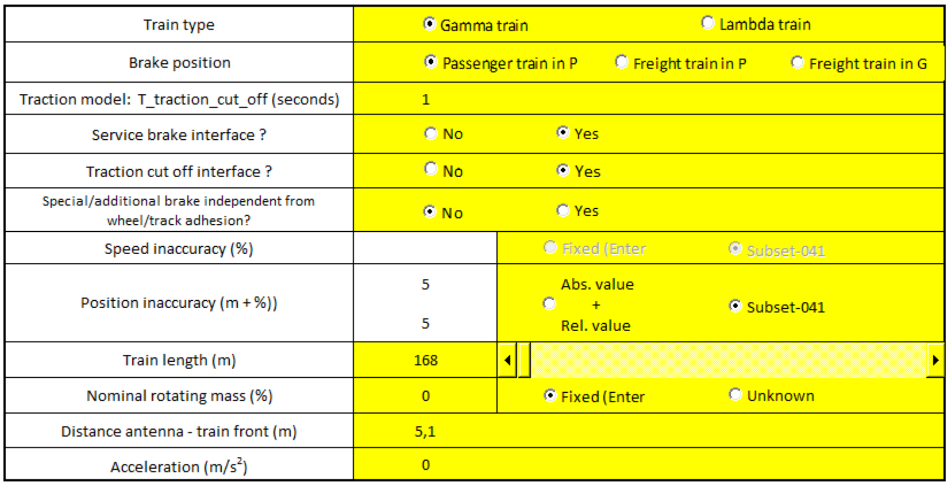
Fig. 3. Concept of propagation blocking of virtual blocks in the event of interrupted communication with train #1 [authors' own study]

4. CAPACITY ASSESSMENT

The study addressed in the paper comprised preliminary examination of the effect of the solution proposed by the authors, assuming virtual blocks (WOB), on the railway line capacity, and more specifically the following:

1. minimum headway times were calculated for train traffic where trackside signalling equipment (without the ETCS) was in operation;
2. minimum headway times were calculated for train traffic where the ATP (ERTMS/ETCS Level 2) system was in operation, implemented over an existing layout of fixed blocks corresponding to those specified in item 1;
3. minimum headway times were calculated for train traffic considering the solution based on virtual blocks; and
4. the results thus obtained were compared, and then the theoretical number of trains per hour was calculated on such a basis.

The length of the braking curve in the ATP system was calculated by a simulation method using the ERA software (braking curve simulation tool v4) for a model train. The train parameters assumed in the calculations have been provided in Fig. 4.



Train type	● Gamma train		○ Lambda train
Brake position	● Passenger train in P	○ Freight train in P	○ Freight train in G
Traction model: T_traction_cut_off (seconds)	1		
Service brake interface ?	○ No	● Yes	
Traction cut off interface ?	○ No	● Yes	
Special/additional brake independent from wheel/track adhesion?	● No	○ Yes	
Speed inaccuracy (%)		○ Fixed (Enter	● Subset-041
Position inaccuracy (m + %))	5 5	○ Abs. value + Rel. value	● Subset-041
Train length (m)	168		
Nominal rotating mass (%)	0	● Fixed (Enter	○ Unknown
Distance antenna - train front (m)	5,1		
Acceleration (m/s^2)	0		

Fig. 4. Parameters of the train simulated in the ERA braking curve simulation tool v4 [authors' own study]

The braking curve model assumed to be applied was the γ model, characterized by a pre-defined value of deceleration for emergency braking of *A_brake_deceleration* = 1.2 [m/s^2], and for service braking – *A_brake_service* = 1 [m/s^2]. What the authors also assumed was a certain reference infrastructure, i.e. spacing of balises at every 1,500 [m] with the positioning inaccuracy of 5 [m], and the ruling gradient of 0 [%]. Some sample results obtained by the simulations have been illustrated in Fig.5.

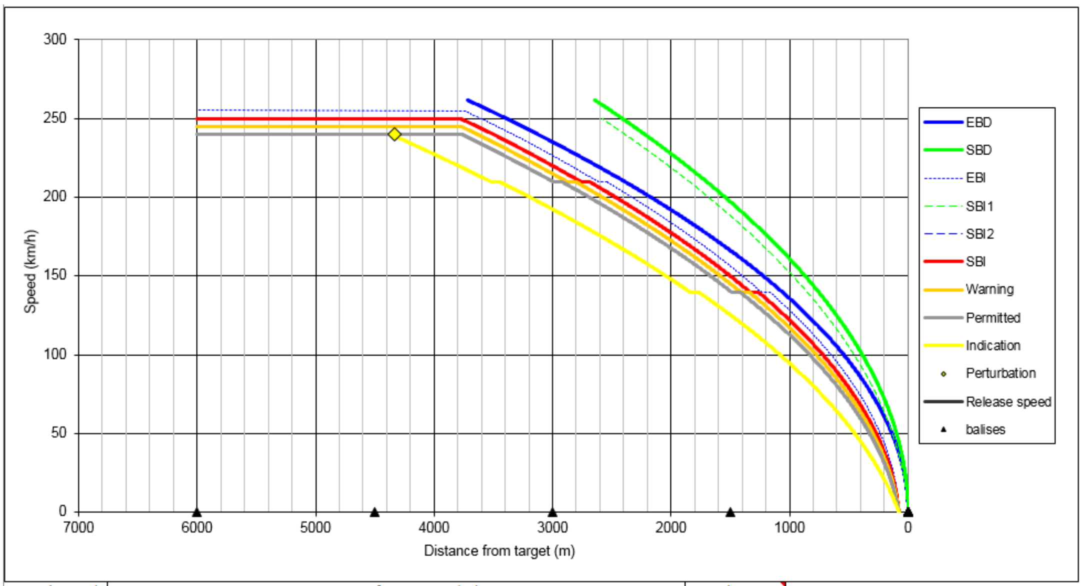
A significant quantity adopted for purposes of further calculations was the permissible speed curve of the *Permitted* type, determining the permissible speed at the given point of the main set route and informing the driver of the need to apply service braking. The characteristic of the distance to the target for the *Permitted* type curve starting from the initial speed has been presented in Fig. 6.

A virtual block should be long enough to enable at least one position reporting by a train, and it should account for the length of the fastest train on the line, i.e.:

$$d_{WOB} = \max\{T_{CYCLOC} \cdot v_{\max}, L_{TRAIN}\} \tag{1}$$

where T_{CYCLOC} determines the cyclic nature of position reports, $v_{\max}$ is the maximum running speed in the given line section, and L_{TRAIN} is the length of the fastest train running on the line.

The minimum theoretical headway time between two consecutive trains, where the train traffic is operated using three-aspect or four-aspect trackside signalling equipment, can be calculated assuming that the successive train should be within the signal sighting distance after the lapse of a minimum time required for the preceding train to release the second (or third, depending on the number of aspects of the trackside signalling equipment) block before the first train.



Initial speed (km/h)	Distance from target (m)							Release speed (km/h)
	Perturbation	Indication	Permitted	Warning	SBI	EBI	StartRSM	
240,00	4337,71	4337,71	3766,26	3632,95	3499,62	3332,95	N/A	0

Fig. 5. Sample results of simulations of braking curves v4 [authors' own study]

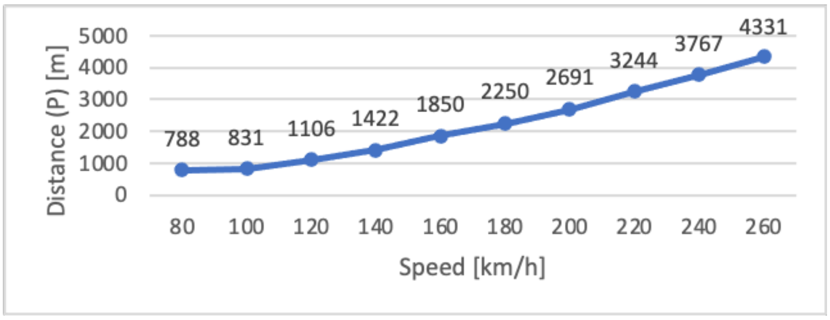


Fig. 6. Distance from the target for the *Permitted (P)* curve depending on speed [authors' own study]

The headway sequence in the case of three-aspect blocking has been shown in Fig. 7, whereas Fig. 8 depicts the same for four-aspect blocking. The minimum headway time for trains controlled by the trackside signalling equipment (without the ETCS) with the t_{HI} three-aspect signalling system can be determined from relationship (2), where SD is the signal sighting distance on a given maximum line speed, L_{Block} is the length of $m-1$ blocks between trains (m denoting the number of aspects of the signalling system), $d_{overlap}$ is the overlap length, L_{TRAIN_2} is the length of the preceding train, t_{IL} is the actuation time of the traffic control equipment, and v is the running speed of train "2". Time t_{IL} is understood as the time from the physical block release after the passage of train "2" until the moment of enforced locking of a new route for train "1" and setting the signal at clear for this train. What should be noted in this respect is that, in the case of four-aspect blocking, block L_{Block} can be shorter than in the case of three-aspect blocking, but not shorter than a half of the required braking distance (L_H).

A new problem is determination of the minimum headway time for trains t_H using fixed blocks and the ETCS. In this case, the distance from the occupied block does not depend on the length of the fixed block (L_{Block}) but on the braking curve calculated by the ETCS. The minimum headway time for trains operated by the ETCS, implemented over a traditional line division into fixed blocks t_{H2}, can be determined from relationship (4), where BC – braking distance to the target according to the *Permitted (P)* braking curve for a given train "1", and t_{IL_ETCS} – time of actuation of the railway traffic control equipment, considering not only the time of releasing and enforced locking of a new route, but also the time of a new train authorization being generated and read by the on-board equipment along with updating the supervised new end of movement authorisation for train "2". Fig. 9 illustrates the headway for a case where the ETCS and fixed blocks are used.

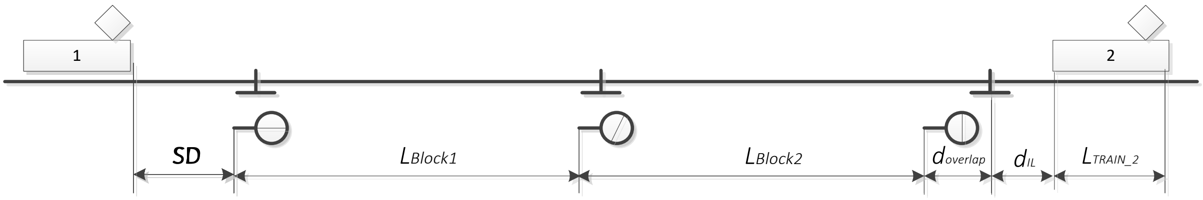


Fig. 7. Headway on three-aspect blocking [authors' own study based on [10]]

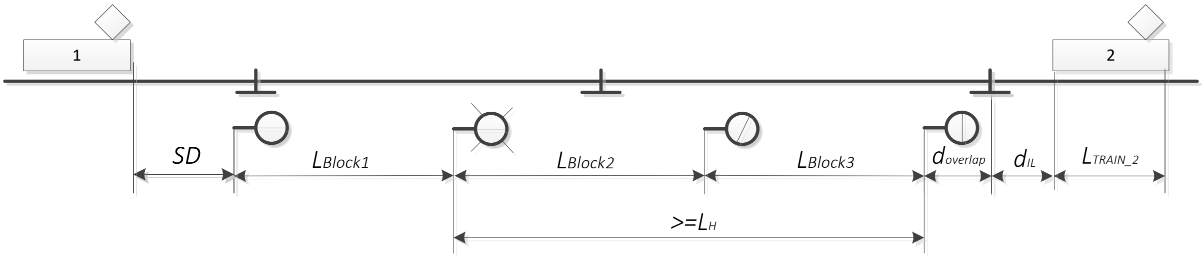


Fig. 8. Headway on four-aspect blocking [authors' own study based on [10]]

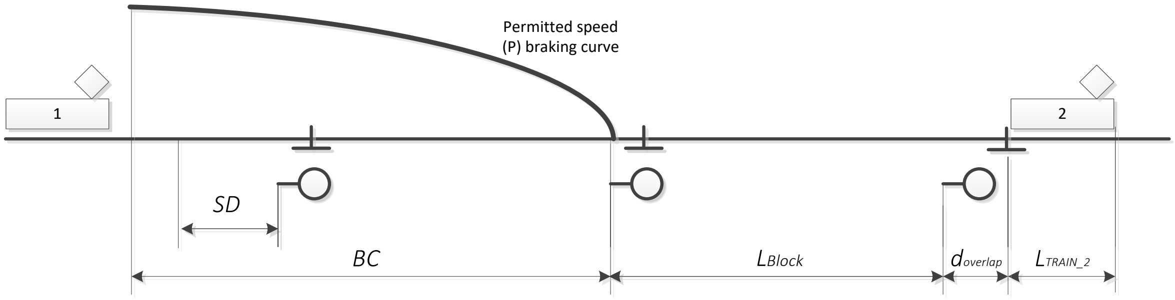


Fig. 9. Headway with the ETCS and fixed blocks used [authors' own study]

$$t_{H1} = \frac{SD + \sum_{i=1}^{m-1} L_{Block} + d_{overlap} + L_{TRAIN\_2}}{v} + t_{IL} \tag{2}$$

$$SD = \frac{10 \cdot v}{3} \tag{3}$$

$$t_{H2} = \frac{BC + L_{Block} + d_{overlap} + L_{TRAIN\_2}}{v} + t_{IL\_ETCS} \tag{4}$$

Where virtual blocks are used, depending on the traffic situation, the preceding train can be controlled by either a fixed block or a virtual block. In the case where virtual blocks t_{H3} are used, the minimum headway time between trains can be determined either from relationship (5), if train “2” is controlled by a virtual block, and from relationship (6) for the train control by a fixed block, where d_{wob} is the length of a virtual section, and T_{CYCLOC} corresponds to the cyclic nature of train position reporting. Fig. 10 illustrates the headway for a case where the ETCS and virtual blocks are used.

$$t_{H3'} = \frac{BC + d_{wob} + L_{TRAIN\_2}}{v} + t_{IL\_ETCS} + T_{CYCLOC} \tag{5}$$

$$t_{H3''} = \frac{BC + d_{wob} + d_{overlap} + L_{TRAIN\_2}}{v} + t_{IL\_ETCS} \tag{6}$$

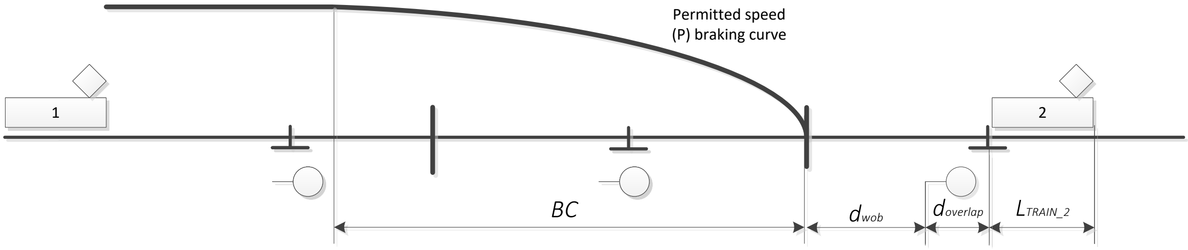


Fig. 10. Headway with the ETCS and virtual blocks used [authors’ own study]

Table 3 and Fig. 11 provide the minimum headway times established for a sample train for model lengths of fixed and virtual blocks with regard to the following cases assumed in the study, concerning the method used for train operations using the railway traffic control system:

- train operations using trackside signalling equipment (without the ETCS) with three-aspect signalling;
- train operations using trackside signalling equipment (without the ETCS) with four-aspect signalling;
- train operations using fixed blocks in the level 2 ETCS, implemented over an existing conventional layout based on three-aspect signalling; and
- train operations based on virtual blocks (the only case assumed being the one represented by relationship [5]).

For the case of train operations based on trackside signalling equipment, theoretical headway times were calculated only up to the speed of 160 km·h^{-1}. Having analyzed the results provided in Fig. 11 and in Table 3, one can conclude that the use of virtual blocks almost always reduces minimum headway times, this being an effect similar to that which is attained by means of four-aspect signalling, yet it does not require installation of additional trackside equipment.

Based on the results of the minimum headway time calculation, what the authors also determined was the theoretical number of trains that could be operated per hour using a specific solution and assuming different maximum line speeds. The results thus obtained have been provided in Table 4 and Fig. 12. Using virtual blocks enables the minimum train headway times to be reduced. In terms of the theoretical number of trains running at a speed of 160 km·h^{-1} operated per hour, the foregoing translates into a difference of 12 trains per hour, which is an effect comparable to that attained by using four-aspect signalling. For higher speeds (above 160 km/h), where only ETCS-based train operation is allowed, the benefit of applying virtual blocks is also evident. The minimum headway time reduction for two successive trains ranges between 14.3 and 6.2 [s] in this case, which translates into the theoretical possibility of operating additional 9÷3 trains per hour compared with a line on which train operations are managed by means of the ETCS using traditional blocks.

Table 3

Headway times calculated for a train running on a line operated using different signalling concepts [authors' own study]

Speed *v* [km·h^{-1}]	Sighting distance *SD* [m]	Braking curve *BC* [m] (ATP)	Virtual block length d_{wob}	Block length L_{Block}	Min. headway time t_{H1} for 3-aspect signalling [s]	Min. headway time t_{H1} for 4-aspect signalling [s]	Min. headway time t_{H2} for fixed blocks with ETCS [s]	Min. headway time $t_{H3'}$ for virtual blocks with ETCS [s]
40	400	420	200	400	130,35	112,35	97,65	84,30
80	400	788	200,00	400	66,68	57,68	67,64	63,96
100	400	831	200,00	700	75,54	62,94	67,36	54,82
120	400	1106	200,00	1000	81,45	66,45	74,13	55,68
140	467	1422	200,00	1000	71,96	59,10	72,31	58,21
160	533	1850	233,33	1300	78,34	63,71	80,21	62,63
180	-	2250	266,67	1300	-	-	79,80	65,50
200	-	2691	300,00	1300	-	-	80,21	68,54
220	-	3244	333,33	1300	-	-	82,37	72,86
240	-	3767	366,67	1300	-	-	83,73	76,01
260	-	4331	400,00	1300	-	-	85,44	79,24

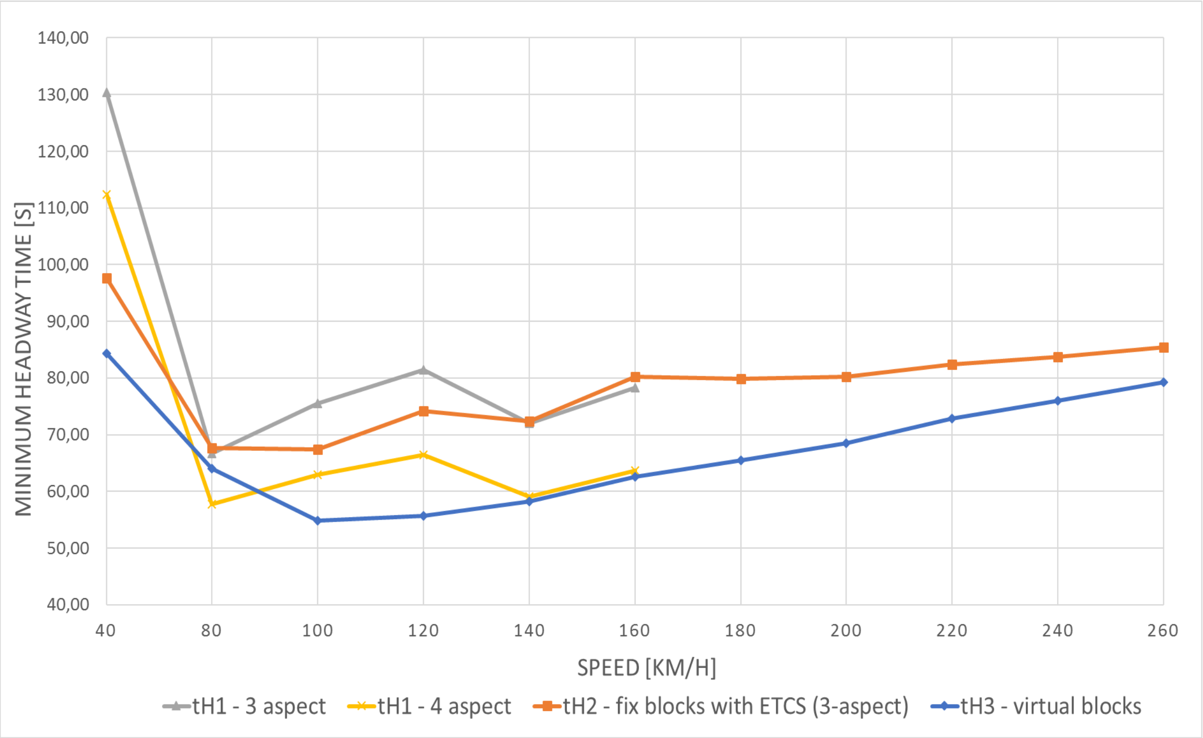


Fig. 11. Results of calculated min. headway times for the signalling concepts subject to analysis [authors' own study]

The calculations performed under the study addressed in the paper consider nominal values of block length. In practice, blocks can be longer as a consequence of local conditions and the need to ensure adequate visibility of trackside signals. For example, the outbound route is typically much longer than the required braking distance in station areas as well.

Table 4

Computational theoretical number of trains per hour on a line operated based on different signalling concepts [authors' own study]

Speed v [km·h^{-1}]	Theoretical trains per hour for 3-aspect signalling [train·h^{-1}]	Theoretical trains per hour for 4-aspect signalling [train·h^{-1}]	Theoretical trains per hour for fixed blocks with ETCS [train·h^{-1}]	Theoretical trains per hour for virtual blocks with ETCS [train·h^{-1}]
40	27	32	36	42
80	53	62	53	56
100	47	57	53	65
120	44	54	48	64
140	50	60	49	61
160	45	56	44	57
180	-		45	54
200	-		44	52
220	-		43	49
240	-		43	47
260	-		42	45

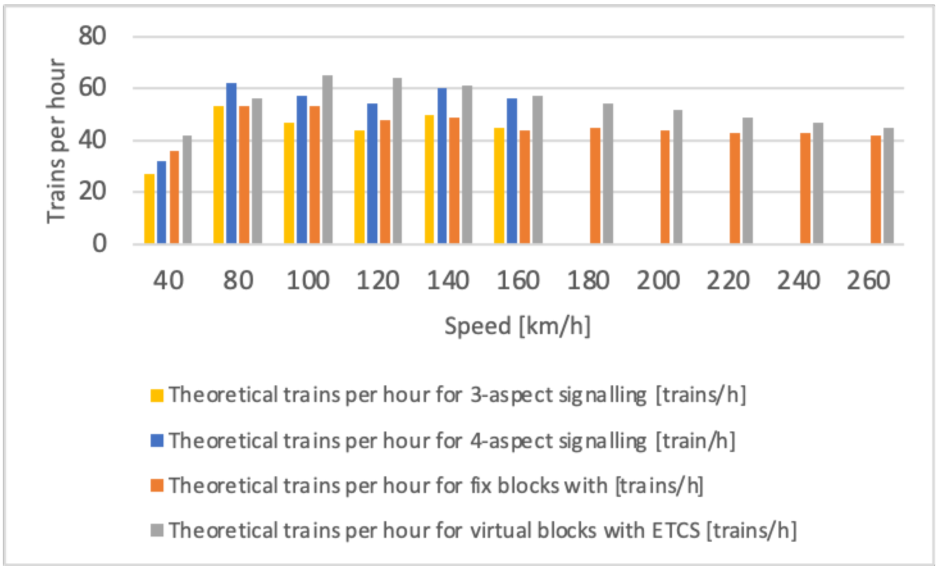


Fig. 12. Number of computational trains per hour depending on speed for the signalling concepts subject to analysis [authors' own study]

5. CONCLUSIONS

The authors of the paper have discussed the effect exerted by application of the ETCS Level 2 on the braking distance vis-à-vis the traditional approach based on standardized braking distances which determine the positioning of trackside signals, and have also presented method for additional block division based on virtual blocks. The virtual blocks can be set to the non-occupancy state based on position reporting by trains without needs to increase train detection devices on the line. What has also been implied is that the traditional formulae should be extended to account for the minimum headway time for purposes of headway calculation by a train equipped with on-board ETCS equipment, making use of the additional division into virtual blocks.

Under the assessment of the effect of the presented solution on the railway line capacity parameters, theoretical minimum headway times were calculated for a theoretical example with minimum block lengths. The calculation results thus obtained confirmed the capacity to have been increased when using virtual blocks compared with the application of the ETCS system with the traditional block division and to train operations by means of trackside signalling equipment (in this case, the assessment was performed only for running speeds up to 160 km/h).

At the same time, while maintaining the existing block division based on conventional non-occupancy detection methods, the authors' solution makes it possible to perform run traffic operations, i.e. to operate trains both equipped and non-equipped with the ETCS.

The authors imply that further research on the proposed virtual block-based solution should comprise establishing a simulation environment where results can be obtained for different train types and for a railway line section covering at least a station and a route.

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