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TRAIN HEADWAY OPTIMISATION USING VIRTUAL BLOCKS

Summary. Although the implementation of a new Automatic Train Protection (ATP) system increases the safety level, it also exerts some impact on the blocking time in block sections, and consequently, on the headway between trains. At the same time, ATP systems introduce a train positioning system based on odometry calculation and reporting back to the trackside system. This paper describes the concept of using virtual blocks based on train position reporting in the ATP system for purposes of non-occupancy determination. Virtual blocks can be used to reduce headways on railway lines without increasing the number of trackside signalling devices. Preliminary capacity assessment was performed to calculate the average headway depending on the signalling system with reference to a case study.
Keywords: railway, signalling, ETCS, ATP, capacity

1. INTRODUCTION

Automatic Train Protection (ATP) systems based on track-to-train radio communication use continuous transmission in the train control process for sending movement authorisations to trains. In this process, trains provide the trackside equipment with reports on their position relative to fixed markers (balises) distributed along the track and reflected by the geographic arrangement of the trackside railway traffic control devices. An example of an ATP system

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featuring track-to-train radio communications is the European Train Control System (ETCS), implemented in Poland with an intent to replace the legacy system - Automatic Train Braking System (*Samoczynne Hamowanie Pociągu, SHP*).

ETCS provides a harmonised description of the data exchanged between the trackside and on-board devices, and of the behaviour of the on-board equipment in terms of safe control of the train movement. For the sake of train movement authorisation, the system retrieves route related data from railway traffic control devices and allocates them to a specific train. In Poland, minimum headways are harmonised and depend on the adopted train braking distances from a specific running speed to a stop [1]. This approach results from the implementation of ETCS over the existing infrastructure as well as the need to manage mixed traffic operations, that is, operations of trains equipped and not equipped with the ETCS devices.

Track-to-train radio communication makes it possible to control train traffic based on moving block sections, where train detection relies only on the reported train position, and where granting movement authorisation is relative to the end of the preceding train. Consequently, the authorisation end may be located at any point of the infrastructure [1]. The reason this solution additionally comprises conventional detection systems is that it enables the detection of unauthorised movements and makes it easier for a system to return to normal operation after being temporarily unavailable.

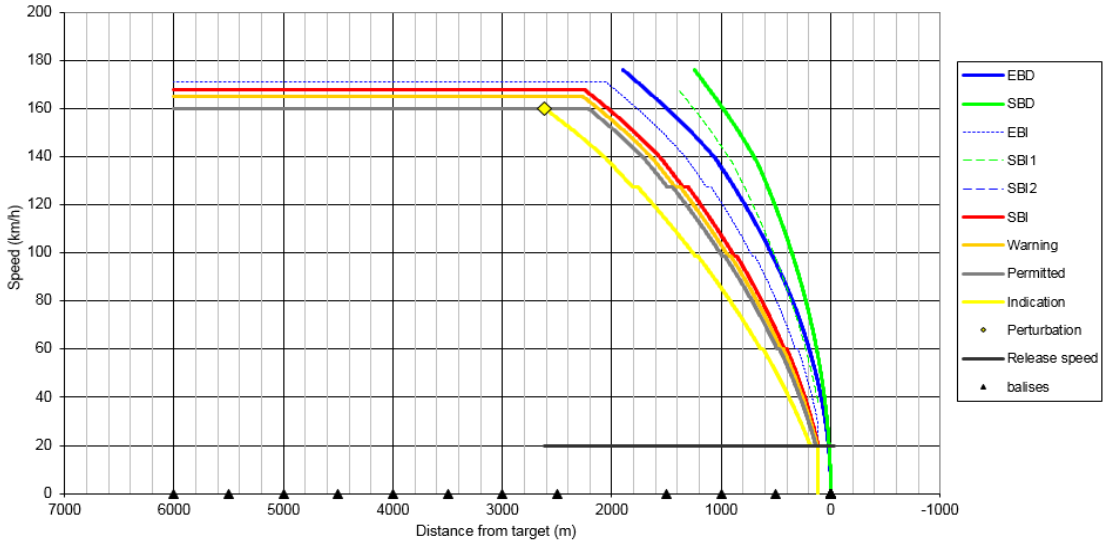
The solution described in this paper involves an additional division of traditional block sections into virtual blocks whose state of non-occupancy would result from a logical state depending, among other aspects, on the position reported by a train. The N number of such virtual blocks may form a real block section featuring – at its beginning and end – conventional occupancy detection systems. According to this solution, the end of the movement authorisation can only be set at certain fixed locations.

The purpose of this paper is to present the train traffic control process based on virtual blocks and to conduct a preliminary assessment of the effect of this solution on the railway line capacity using a chosen railway station as an example.

2. STATE OF THE PROBLEM AND LITERATURE REVIEW

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 to road transport. An aspect, which is considered very significant for the development of rail transport, is its low-carbon nature compared to road transport, as well as its lower overall negative environmental impact [2-4]. The traffic operated in the Polish railway network, where the ETCS Level 2 is currently in operation, is of a mixed character, which applies to trains both equipped and non-equipped with on-board ETCS devices. Such a traffic structure may increase its heterogeneity due to the difference between the train speed supervision based on the braking characteristic calculated by the ETCS (commonly referred to as a braking curve) and the driver’s driving style and behaviour vis-à-vis the trackside signalling equipment. This, in turn, can lead to an increase in the headway time and distance between two consecutive trains. As evidenced in paper [8], heterogeneity is determined by the index of homogeneity of blocking time, the homogeneity in terms of time buffers between consecutive trains, and the homogeneity in terms of the direction of movement of individual trains.

Fig. 1 illustrates sample braking characteristics according to the model applied under ETCS, established using the ETCS braking curve model, as described in specification [7]. The model train used for the simulation is characterised by the share of real braking mass used for emergency braking of λ_0 equalling 140 [%], which corresponds to the minimum value required for a braking distance of 1,300 [m] (assuming the ruling gradient of 0 [‰]) according to the traditional approach, and as per Appendix 1 to the Ir-1 manual [5, 6]. The simulation result thus obtained implies that ETCS will instruct the driver in terms of the need to apply braking at a distance of 2,617.75 [m] from the authorisation endpoint, while if there is no response, the system will respond by initiating full service braking at 2,035.22 [m] before the place where the authorisation ends.



Initial speed (km/h)	Distance from target (m)							Release speed (km/h)
	Perturbation	Indication	Permitted	Warning	SBI	EBI	StartRSM	
160,00	2617,75	2617,75	2212,95	2124,11	2035,22	1767,48	113,81	20

Fig. 1. Braking curves calculated by *Braking curves simulation tool v 4.2* for the model train [author's study]

The literature extensively describes the models applied to assess the capacity of railway lines, consequently used in both simulation and analytical methods [9-14]. An assessment comparing simulated and real routes of a train equipped with the ATP system was discussed in the work [15]. An example of the impact exerted by an extended braking distance (Fig. 1) on the characteristics calculated by ETCS relative to the traditional minimum block section lengths are presented in Fig. 2 using the model described in paper [9] for blocking of individual block sections. The longer braking distance calculated by the ETCS system based on the assumed division into block sections may cause the given block to be occupied for a longer time or make it necessary to extend the headway. Where an opposite situation is the case, and the block section is longer than the braking distance calculated by the ETCS system, the headway may be shorter than that which applies to operations under a traditional signalling system.

The literature refers to various ways to increase railway capacity using various technical or optimisation solutions. The research [16] discusses how the length of block sections can be chosen automatically for purposes of the ETCS. Using an algorithm for the dynamic optimisation of train headway time was described in the study [17]. An option of additionally increasing the railway line capacity if moving block sections are used was discussed in paper [1818], arguing that a relative braking distance, as it is commonly referred to, should be considered in the process of separating consecutive trains in movement. Where this is the case, it is assumed that the preceding train, even if it applies emergency braking, will continue to move because of its inertia. According to this approach, the authorisation granted to the next train can account for the foregoing, making it possible to reduce the headway distance and time. Such a solution requires an additional infallible channel of communication between trains. The research [19] speaks of reducing the headway between trains even more, suggesting that one should apply a virtual coupling, that is, coupling two consecutive trains virtually for their control process. In solutions such as those proposed, using even more reliable communication technologies and developing methods for even more accurate train positioning seems to be the key problems.

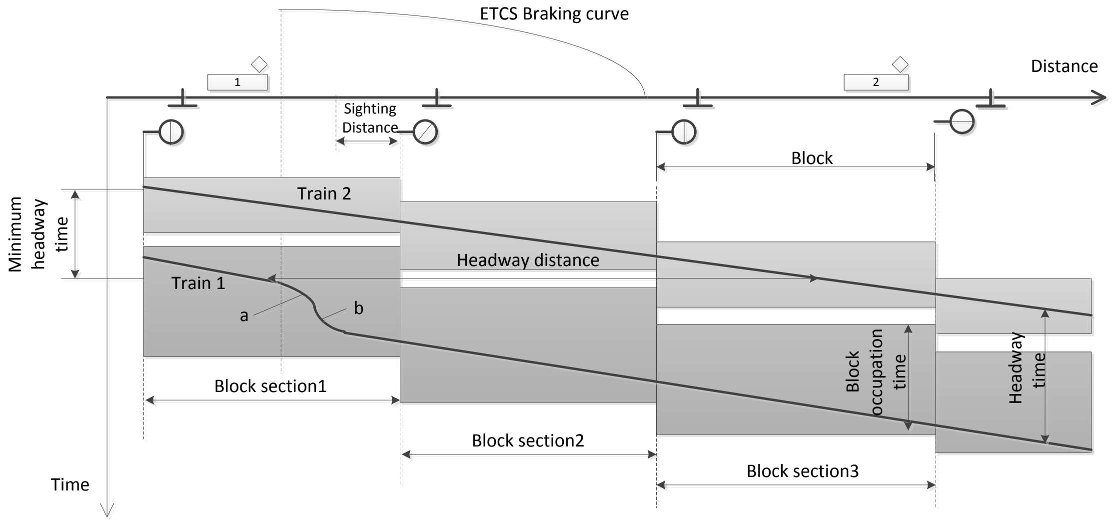


Fig. 2. Effect of a more restrictive braking curve in the ETCS against traditional headways, where *a* corresponds to train deceleration and *b* to train acceleration [author's study based on [9, 10]]

3. CONCEPT OF VIRTUAL BLOCKS

The concept of virtual blocks (VB) implies additional division of fixed block sections for ETCS trains. In order not to increase the quantity of the trackside equipment, it has been proposed that this division should be based on VB, which do not require traditional non-occupancy detection systems.

The set of *n* VB would comprise a fixed block section as per the traditional approach, that is, terminated by physical non-occupancy confirmation devices. The logical state of such a virtual block could be defined as a logical sum of:

- the physical state of non-occupancy of a fixed block that is part of the locked route,
- the train location as derived from its reported position.

Such a solution could make it possible to decrease the headway separating two consecutive ETCS trains in movement and give the possibility to operate non-equipped with the ETCS devices in trains. The concept of VB is illustrated using the example shown in Fig. 3, where an additional division of a three-aspect block signalling system featuring light signals has been proposed.

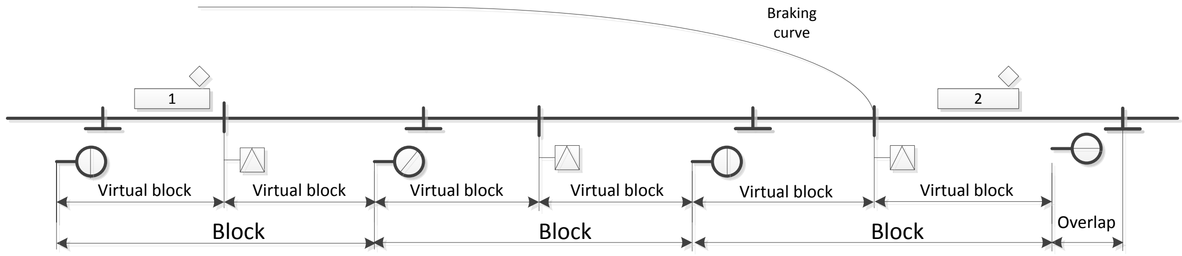


Fig. 33. Signalling system layout with 3-aspect signalling (line block) and VB [author's study]

Besides developing the block division on the route, another viable alternative is to apply this solution within station areas so as not to create bottlenecks, as they are commonly referred to. For example, it is possible to break down an outbound route from the station, since its length is traditionally much longer than the braking distance.

4. PRELIMINARY CAPACITY ANALYSIS (CASE STUDY)

The model setup used for purposes of capacity assessment with the application of the virtual block solution is the outbound route from the Bolesławiec (Bc) station towards the Bolesławiec-Zebrzydowa (Zb) route (Fig. 4). In this case, the lengths of the block sections (including the outbound route) are significantly longer than the typical braking distance assumed for the speed of 160 [km·h^{-1}] equalling 1,300 [m].

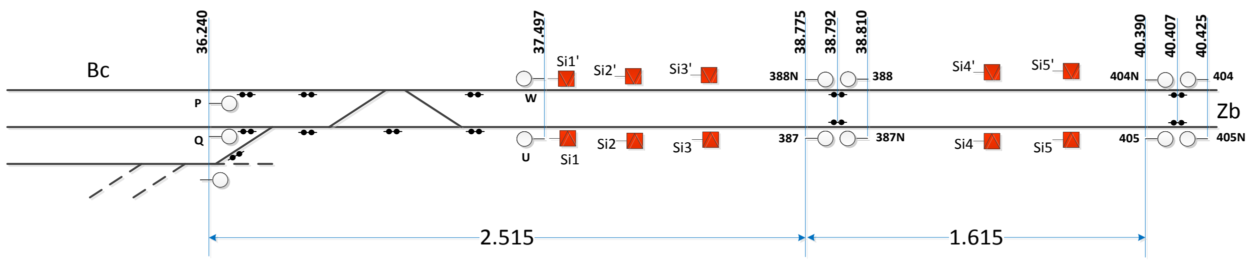


Fig. 4. Example of the signalling system layout at the Bolesławiec (Bc) station with the proposed additional VB on the outbound route towards the Zebrzydowa (Zb) station [author's study]

Table 1 and Fig. 5 show the minimum headway times established for the train analysed in the case study for the following conditions:

- the outbound route is split in real life into fixed block sections where the train operations are managed by three-aspect trackside signalling equipment;
- ETCS Level 2 implemented at the existing block sections;
- VB in use.

The data analysed in this case study concern movement without stopping. The proposed division into VB covers the outbound route from the P/Q exit signals as long as to the new movement authorisation end markers installed near the U/W entry signals (Figure 5). The minimum headway times, given by relationships (1–3), have been determined as follows:

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

$$t_{H2} = \frac{BC + L_{Block} + d_{overlap} + L_{TRAIN\_2}}{v} + t_{IL\_ETCS} \tag{2}$$

$$t_{H3} = \frac{BC + d_{VB} + L_{TRAIN\_2}}{v} + t_{IL\_ETCS} + T_{CYCLOC} \tag{3}$$

where: t_{H1} is the minimum headway time for two consecutive trains running in traditional block sections, t_{H2} is the minimum headway time for two consecutive trains in the case where the ETCS determines the beginning of braking until the authorisation end, t_{H3} is the minimum headway time where VB are used, 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 time of actuation of the traffic control equipment, v is the running speed of train "2", and BC is the length of the braking distance to the target according to the *Permitted speed* braking curve for the given train "1".

Tab. 1

Computational headways for a train running on an outbound route from the Bc station [author's study]

Speed v [km·h^{-1}]	Sighting distance *SD* [m]	Braking curve *BC* [m] (ATP)	t_{H1} for 3-aspect signalling [s]	Theoretical t_{ph} for 3-aspect signalling [train·h^{-1}]	t_{H2} for fix blocks with ETCS [s]	Theoretical t_{ph} for fix blocks with [train·h^{-1}]	t_{H3} for VB with ETCS [s]	Theoretical t_{ph} for VB with ETCS [train·h^{-1}]
40	400	420	**430.05**	8	**207.00**	17	**84.30**	42
80	400	788	**216.53**	16	**122.31**	29	**63.96**	56
100	400	831	**173.82**	20	**100.30**	35	**54.82**	65
120	400	1,106	**145.35**	24	**92.58**	38	**55.68**	64
140	467	1,422	**126.73**	28	**88.12**	40	**58.21**	61
160	533	1,850	**112.76**	31	**87.30**	41	**62.63**	57

The value of time t_{IL} was calculated for a time starting from the physical block section 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. t_{IL_ETCS} is the 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 authorisation being generated and read by the on-board equipment along with updating the supervised new end of movement authorisation for train

“2”, d_{VB} is the virtual block length, and T_{CYCLOC} corresponds to the cyclic nature of the train position reporting.

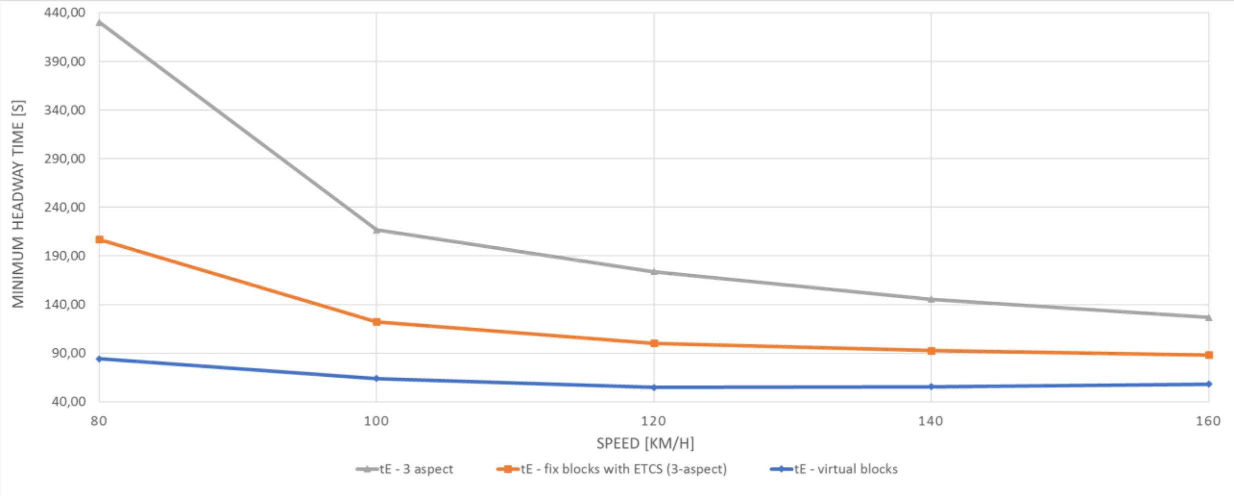


Fig. 5 Results of calculated min. headway times for the signalling concepts subject to analysis [author’s study]

Based on the results of the minimum headway time calculation, the author also determined the theoretical number of trains that could be sent out per hour using a specific solution, assuming different maximum line speeds (Figure 6).

Having analysed the results thus obtained, it should be noted that in the case of the additional division of the outbound route from the station and the first block section, it is possible to increase the theoretical number of trains equipped with the relevant on-board equipment per hour from 25 [trains per hour] (at 40 km/h of running speed) to 16 [trains per hour] (at 160 km/h). Moreover, where this is the case, it is easy to recognise the benefit of using ETCS, even based on the traditional and fixed division of the outbound route and the first block section, which results from the length of the main set route from exit signals P/Q to the first blocking signals 388N/387, which is longer than the braking curve calculated by the ETCS.

5. APPLICABILITY DISCUSSION

Increase of the line capacity with the traffic control using virtual blocks requires that most of the trains will be equipment with additional device for train integrity monitoring and the entered to the system train length is confidence and validated. The purpose of this is to provide to trackside part of the system the confident location of the rear of the train and that the train is complete. Management of this device as well as putting correct data related to the train length require high safety culture in train operator company nevertheless should not base only on human factor. Especially for non-multiple-unit trains, the train length already entered by driver, should be validated e.g. by additional plausibility check compared to amount of carriages or by axle counters to confirm the train length in places where the trains make start of mission.

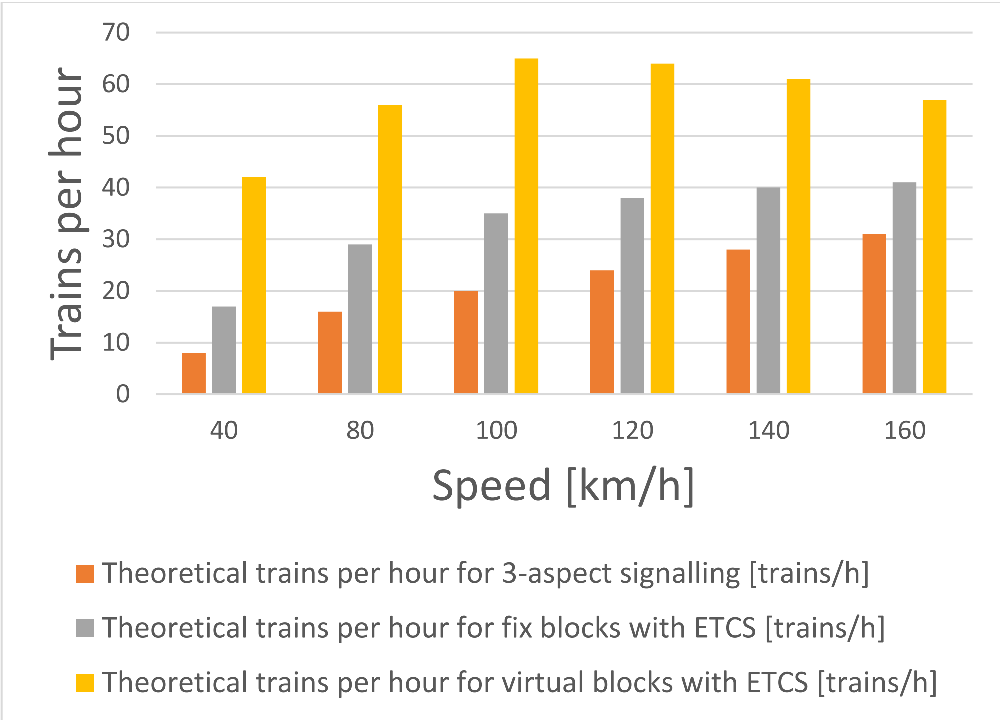


Fig. 6. Calculated number of trains per hour depending on speed for the case study analysed [author's study]

6. CONCLUSIONS AND FUTURE WORK

This paper discusses the process of train traffic control based on VB and addresses a preliminary assessment of the effect of this solution on the railway line capacity.

Under the preliminary assessment of the effect of the solution with virtual blocks on the railway line capacity parameters, the theoretical minimum headway times and the theoretical number of trains per hour were calculated for the chosen station's outbound route. The calculation results thus obtained confirmed the capacity increase achieved using virtual blocks compared to the application of ETCS with the traditional block section division and against train operations using the trackside signalling equipment (in this case, the assessment was performed only for running speeds up to 160 km/h).

While maintaining the existing block section division based on conventional non-occupancy detection methods, the presented solution makes it possible to perform mixed traffic operations, that is, to operate trains both equipped and non-equipped with ETCS.

The author implies that further research on the proposed 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. Such a simulation should consider the train movement dynamics because of the variable speed profile and train stopping either at a station for maintenance purposes or at an on-route stop.

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