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Simulation of Throughput Capacity for Line with Dynamic Block Sections

V. Taurienė

Department of Control Technology, Kaunas University of Technology, Studentu g. 48, LT-51367 Kaunas, Lithuania

T. Magyla

JSC Lithuanian Railways, Branch "Kaunas railways infrastructure", Čiurlionio g. 14B, LT-44360 Kaunas, Lithuania

Introduction

Most of existing automation, signalling and telecommunications systems in accession states are worn enough and require renovations [1]. In accordance with Technical Specifications for Interoperability [2-3], accession states will be getting prepared for migration from class B control, command and signalling systems to class A. For this migration process to be efficient, there are many different solutions. Therefore it is evident that some of the infrastructure and rolling stock operators will be more successful in this process, than the others, thus increasing competition between themselves. Throughput capacity is considered to be one of the most important factors for successful competition. Though infrastructure (especially in the 1520mm gauge countries) is quite similar, there exist many different approaches for increasing throughput capacity.

The issue of throughput capacity for lines with automatic block system (having block sections with a certain fixed length) was investigated earlier [4 – 5]. Later, a train control model with dynamic block sections was developed [6], and some of advantages of such development were emphasized.

The aim of this work was to find out the interdependence between speed of train and a throughput capacity for lines with implemented dynamic block sections, and to compare it with characteristic interdependence of a line with automatic block system; and also, to decide about the optimal train speed for reaching maximum throughput capacity.

Throughput capacity for lines with automatic block system

Throughput capacity for a single-track road with ordinary automatic block system is denoted by the following expression [4]:

$$\Pi_{AB} = \frac{n \inf_{i} v_i}{2L_{BR}(n-1) + nl + L}; \qquad (1)$$

where Π_{AB} – is a throughput capacity of a section with implemented automated block system, in trains per hour; L_{BR} – a length of block section, in km; L – a length of a line, in km; l - average length of a train, in km; v – is the average train speed at the line, km/h.

For use in our investige Kužiai – Kretinga railways road section with semiautomatic block system was selected. If automatic block system were installed on this line, throughput capacity Π_{AB} would depend on n (a number of trains in a "packet") (see Table No.1) [4].

Table 1. Dependence of Π_{AB} from *n*

n, number of trains	Π_{AB}, trains per hour
1	4,87
2	7,56
3	9,28
4	10,47
5	11,34

Table 2. Dependence of Π_{AB} from v_0

v_0, km/h	Π_{AB}, trains per
60	12
80	16
100	20
120	24
160	32

However, more desired is dependence of the throughput capacity Π_{AB} and train speed v_0 (see Table 2), calculated by applying formula (1), under assumption that a length of a block section L_{BR} is equal to 2,25 km, the average length of a train is l=500 m, and the total delay because of the human factor and duration of preparation of braking system is equal to 5 s.

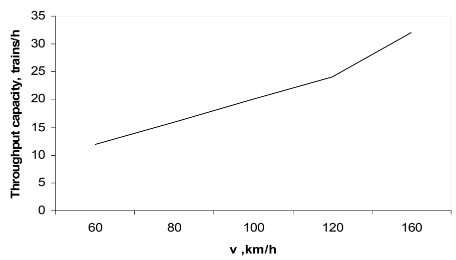

Fig. 1. Dependence between throughput capacity and train speed, for the line with automatic block systems

Dependence of the throughput capacity Π_{AB} and train speed v_0 for lines with automatic block systems, from Table 2., is seen in Fig. 1., and clearly denotes the monotonously rising of this dependence.

Throughput capacity for lines with dynamic block sections

An interval-based train control model, using dynamic block sections was developed [6] in order to optimise train traffic flows in lines. This approach was based on the idea to use block sections with variable lengths, depending on the traffic density. Control of traffic is performed from a Centralized traffic control centre (CTC), which via optical network is connected to several radio block centres (RBC). Trains communicate by the help of GSM-R communications, and GPS positioning systems together with trackside equipment are used to define the location of a train [7-8].

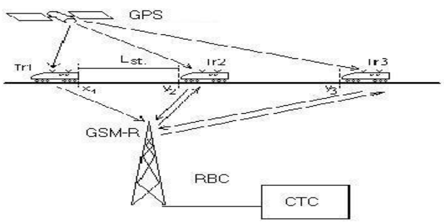

Fig. 2. Control of traffic, based on dynamic block sections and GSM-R in combination with GPS (GALILEO)

Throughput capacity Π_{mbr}, expressed in trains per hour, for such a line (Fig. 2.) with dynamic block sections is calculated by applying the following formula:

$$\Pi_{mbr} = \frac{v}{l + L_{st}}, \qquad (2)$$

where v –- is speed of train, km/h; $L_{st.}$ – train braking distance, km; l – average length of a train, in km.

A methodology for calculating braking distance [9] could be applied.

Train braking distance $L_{st.}$, that is, the overall distance from the moment when a command for braking was initiated till the complete stop of a train is denoted by the following:

$$L_{st.} = L_p + L_d, \qquad (3)$$

where L_p is initial distance, which train pass without applying brakes, during which brakes are only being prepared to be applied, in km; L_d – the real braking distance, km.

The abovementioned initial distance depends on the speed of a train v_p before receiving the command for braking, km/h, and time t_p, in hours, during which the train was being prepared for applying brakes.

The initial distance, passed during preparation of brakes, L_p is as follows:

$$L_p = \frac{v_p t_p}{3{,}6} = 0{,}278 v_p t_p, \qquad (4)$$

here t_p for freight trains with a length from 200 to 300 axles is calculated by applying the following:

$$t_p = 10 - \frac{15 i_c}{b_{st}}, \qquad (5)$$

$$i_c = w_i + w_r, \qquad (6)$$

where i_c – is relative friction, which depends on the road inclination and turning curves, that is, w_i – is acclivity of a road (measured in $\%_{00}$), with sign „+“ for acclivity and “–“ sign for descents; $w_r = \frac{700}{R}\frac{l_{kr}}{l}$, where R is curve radius, km; l_{kr} is length of a curve, km; l – length of a train, km; b_{st} is relative train braking force, kg/t, that is, a braking force distributed for 1 ton of train’s weight. b_{st} is denoted by the following:

$$b_{st} = \frac{\Sigma B_{st}}{Q}, \qquad (7)$$

where ΣB_{st} is the overall braking force of all the drags, kg/t; Q – weight of a train, in tons.

We could apply the following technique to calculate the overall braking force of all the drags. The force K impacts the drag of a wheel, and as a result of this, a frictional force B_1 appears, which is expressed by the following formula:

$$B_1 = K\varphi_k, \qquad (8)$$

where φ_k is a frictional coefficient, describing interaction between drag and wheel mechanism.

By applying elementary laws of mechanics, we could prove that for a single drag, the braking force is as follows:

$$B_t = B_1 = K\varphi_k. \qquad (9)$$

From formulas (7, 8 and 9) we obtain the following:

$$b_{st} = \frac{\varphi_k \sum K}{Q} = \varphi_k \zeta, \qquad (10)$$

where $\zeta = \frac{\sum K}{Q}$ is a coefficient of compression characterising the compression force, influencing drags.

If a centralized automatic braking system is used, additional reaction time should be added to the brakes preparation time t_p, for conventional rolling stock, used by LG, it has a fixed value of 12s:

$$t_{aut.st} = t_p + 12, \qquad (11)$$

where $t_{aut.st.}$ is the overall time for preparing automatic braking system, and t_p are in seconds. It should be noted, that for convenience of calculations, dimension of $t_{aut.st.}$ is usually in hours, converted from seconds.

The real braking distance, in the speed interval from v_i to v_{i+1} is as follows:

$$L_d = \sum_{i=0}^{n} \frac{500(v_i^2 - v_{i+1}^2)}{\xi(b_{st} + w_{0L} + i_c)}, \tag{12}$$

where n is a number of intervals, into which the band of speed $v_0 - 0$ is split, in which integration is changed with a procedure of "stepped approximation" (in accordance with speed v). In order to obtain the desired precision, it would be recommended to choose n so that the following would correct: $(v_i - v_{i+1}) \leq 10 km/h$; where v_i is speed of a train at the beginning of the *i*–th calculation interval, km/h; v_{i+1} - is speed of a train at the end of the *i*-th interval, it is equal to a speed at the beginning of (*i*+1) – th interval, km/h; v_0 - is a speed of a train before the braking, in km/h; $v_{n+1} = 0$ - is speed when stopped; ξ – velocity factor which characterizes inertia of spinning masses; b_{st} is found from formula (7), in which $v \to \bar{v}_i = \frac{v_i + v_{i+1}}{2}$; i_c - is calculated from formula (6); w_0 – is a relative coefficient, characterizing opposition for train movement, kg/t; ξ is gravity acceleration, expressed in km/h^2, during calculation of which, a coefficient of spinning masses γ is assessed, too [9]. In practice, ξ can be expressed as follows:

$$\xi = 9{,}81 \frac{(3600)^2}{(1000)^2(1+\gamma)} \cong 120, \tag{13}$$

where $\gamma \cong 0{,}06$ is assumed for the case of passenger and freight trains [10].

A relative coefficient, characterizing the opposition to train's movement depends on many factors: shape of the wheel, gauge head construction, type of wagon bearing (gliding or rolling) and so on. The w_0 (kg/t) is usually expressed in empiric expressions like the following two [9]:

w_{0L} for locomotives:

$$w_{0L} = 2{,}4 + 0{,}011v + 0{,}00035v^2, \tag{14}$$

w_{0V} for conventional freight four-axle wagons with rolling bearings:

$$w_{0V} = 0{,}7 + \frac{8 + 0{,}1v + 0{,}0025v^2}{q_0}, \tag{15}$$

where q_0 is the average load of the wagon axle, in tons.

With regard to the above mentioned, simulation was performed and dependence was found between the train speed and line throughput capacity (for lines with dynamic block sections). For simulation the average weight of freight trains was chosen to be $Q = 4000$t, and corresponding length $l = 1{,}090$ km. A distance between trains was presumed to be equal to $L_{st.}$ and was calculated by applying formula (3) (see Fig. 3.)

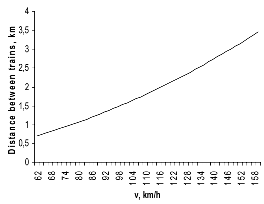

Fig. 3. Resulted distance between trains

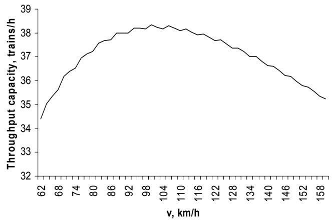

Fig. 4. Dependence between throughput capacity and train speed, for the line with dynamic block sections

Duration of simulated observation was chosen 24 hours (so that to be able to compare a number of trains, passed each hour, with existing statistics, if needed).

From obtained simulation results (see Fig. 4.) we see, that throughput capacity is not a monotonously rising function, and has an extreme point. From this extreme point we can decide the optimal train speed, under which the maximal throughput capacity could be reached. The usable nominal speed is specified in the directive [11], the existing typical value is 100 – 120 km/h. By a chance the extreme point matches well the existing speed interval, therefore it would be purposeful to use namely this speed.

Conclusions

1. Throughput capacity, which is one of the most important operational characteristics, for lines with automatic block systems, is a monotonously rising function of a train speed.
2. Throughput capacity of a line can be increased, by implementing train traffic control based on the approach of dynamic block sections.
3. Throughput capacity of railway lines with dynamic block sections differs from conventional throughput capacity in lines with automatic block system, because it is not monotonously rising speed function.
4. Throughput capacity Π_{mbr} has extreme point.
5. Based on the location of this extreme point we can decide the best acceptable train speed under which the maximal throughput capacity will be obtained.

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Dauguma automatikos, signalizacijos ir telekomunikacijų sistemų būsimosiose ES šalyse yra pakankamai susidėvėję ir reikalauja atnaujinimo. Sutinkamai pagal Techninės sąveikos specifikacijas, yra numatytas perėjimas nuo B lygmens kontrolės, valdymo ir signalizacijos sistemų prie A lygmens. Pralaidumas yra viena iš svarbiausių eksploatacinių charakteristikų. Nors infrastruktūra (ypač šalyse su 1520mm vėže) yra ganėtinai panaši, tačiau egzistuoja daugybė skirtingų būdų pralaidumui padidinti. Šio darbo tikslas buvo surasti priklausomybę tarp traukinio greičio ir pralaidumo tarpstočiams su įdiegtomis judriųjų blokuojamųjų ruožų sistemomis, ir palyginti su charakteringa tarpstočio su automatine blokuotės sistema priklausomybe; nustatyti optimalų traukinio greitį maksimaliam pralaidumui pasiekti. Šis straipsnis pateikia detalius traukinio stabdymo kelio, greičio ir įtakojančiųjų jėgų skaičiavimus, nes tai iš esmės įtakoja pralaidumą. Yra pademonstruojama, kad galima pasiekti didesnį pralaidumą, įdiegus judriuosius blokuojamuosius ruožus. Pralaidumas judriųjų blokuojamųjų ruožų atveju nėra monotoniškai auganti greičio funkcija, skirtingai nuo automatinės blokuotės sistemų. Pralaidumas turi ekstremumo tašką. Pagal šį ekstremumo tašką gali būti nustatytas traukinio greitis, prie kurio yra pasiekiama geriausia pralaidumo reikšmė. Il. 4, bibl. 11 (anglų k.; santraukos lietuvių, anglų ir rusų kalbomis).

V. Taurienė, T.Magyla. Simulation of Throughput Capacity for Line with Dynamic Block Sections // Electronics and Electrical Engineering. - Kaunas: Technologija, 2004. – No. 4 (53). – P.90-93.

Most of existing automation, signalling and telecommunications systems in EC accession states are worn enough and require renovations. In accordance with Technical Specifications for Interoperability, migration from class B control, command and signalling systems to class A is foreseen. Throughput capacity is considered to be one of the most important operational characteristics. Though infrastructure (especially in the 1520mm gauge countries) is quite similar, there exist many different approaches for increasing throughput capacity. The aim of this work was to find out the interdependence between speed of train and a throughput capacity for lines with implemented dynamic block sections, and to compare it with characteristic interdependence of a line with automatic block system; and also, to decide about the optimal train speed for reaching maximum throughput capacity. This paper describes in details calculation of train braking distance, speed and influencing forces for conventional lines with automatic block systems and for lines with dynamic block sections, as it considerably influences the throughput capacity. It is shown, that a greater throughput capacity can be reached if dynamic block sections are implemented. Throughput capacity in the case of dynamic block sections is not a monotonically rising speed function; not like for automatic block systems. Throughput capacity has extreme point. From this extreme point the train speed can be determined, under which the best value of a throughput capacity can be reached. Ill. 4, bibl. 11 (in English; summaries in Lithuanian, English, Russian).

В. Таурене, Т. Магила. Моделирование пропускной способности перегона с мобильными блок участками // Электроника и электротехника. – Каунас : Технология, 2004. - № 4(53). – С.90-93.

Большинство из существующих в странах ЕС систем автоматики, сигнализации и телекоммуникации являются уже достаточно изношенными и требуют обновления. В соответствии с техническими спецификациями взаимодействия предусмотрен переход систем управления и сигнализации с уровня контроля В на уровень А. Пропускная способность является одной из самых важных эксплуатационных характеристик. Хотя инфраструктура (особенно в странах с колеёй 1520мм) довольна похожа, однако существует масса различных способов увеличить пропускную способность. Целью этой работы было найти зависимость между скоростью поездов и пропускной способностью с внедрёнными системами динамически блокируемых участков и сравнить с характерной зависимостью системы автоматической блокировки, а также установить оптимальную скорость для достижения максимальной пропускной способности. Эта статья предоставляет детальные рассчёты тормозного пути поезда, скорости и влияющих сил, поскольку по существу, именно от этого зависит пропускная способность. Продемонстрировано, что можно достигнуть большей пропускной способности, внедрив динамическую блокировку участков. В отличие от систем автоматической блокировки участков, пропускная способность в случае динамачески блокируемых участков не является монотонно растущей функцией скорости. Пропускная способность имеет точку экстремума. Посредством этой точки экстремума можно будет установить такую скорость поездов, при которой достигается лучшее значение пропускной способности. Ил. 4, библ. 11 (на англиском языке; рефераты на литовском, английском и русском яз.).