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Professional paper

Influence of Train Stopping Distance and Overlap on the Railway Traffic Safety

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Abstract – **Traffic safety should always be prioritized in all traffic systems. As the railway is a high-level complex technical and technological system, many factors affect its safety. Two factors that are the subject of research in this paper are train stopping distance and overlap.**

Keywords – **Railway Traffic Safety, Train Stopping Distance, Overlap.**

I. Introduction

The main objective of this paper is to present train stopping distance, overlap, and their influence on railway traffic safety from the perspective of traffic and transport engineers.

Train stopping distance is an important factor not only in the aspect that covers the length that the train travels until the stop, but also is important for the railway system in general because it's used when designing certain parts of the system.

Another factor that imposes itself when traffic safety is a topic, is overlap. Similarly as stopping distance, besides the safety aspect, the overlap is used when designing signalling system.

This paper doesn't consider high-speed train systems.

II. Train Stopping Distance

Train stopping distance is defined as the distance that the train travels from when the driver detects an obstacle (or signal) and applies the brake until a complete stop. Values of stopping distances on Republika Srpska Railways are shown in Table I [13].

Table I
VALUES OF STOPPING DISTANCES

Length	Type
1500 m	160 km/h
1000 m	120 km/h
700 m	100 km/h
400 m	shunting operations

Mathematically, the above definition of the stopping distance can be expressed as Eq. (1):

$$l_{sd} = l_{rd} + l_{bd} \; [m] \tag{1}$$

where:

- l_{rd} is reaction distance and
- l_{bd} is braking distance.

As shown in Eq. 1., stopping distance consists of two parts: reaction distance and braking distance.

Reaction distance length depends on reaction time and movement speed, as shown in Eq. (2):

$$l_{rd} = t_{rt} \cdot v \; [m] \tag{2}$$

where:

- t_{rt} is reaction time and
- v is the train movement speed (converted to *m/s*).

Reaction time is time that passes from the moment when the driver detects an obstacle (or signal) to the moment of applying brakes. This time consists of two parts [4]: driver reaction time and brake delay time. The question that is often the topic of discussion, especially during the expertises of traffic accidents, is whether the train driver could react on time and avoid the collision. So, at what moment the train driver will react depends on when he'll notice the obstacle (or signal). That depends on several factors. Some of them are:

- train driver attention while driving,
- train movement speed,
- weather conditions,
- appearance characteristics of obstacles (dimensions, brightness, markings, colors, etc.),
- time of day (day time or night time),
- terrain configuration,
- rail line position and line gradient.

By some researches, driver reaction time is between 0.5 and 1 second [16]. Values of distances traveled during driver response time are given in Table II.

Table II
VALUES OF DISTANCES TRAVELLED BY TRAIN DURING DRIVER REACTION TIME

v \ t_{dr}	0.5	0.6	0.7	0.8	0.9	1
10	2	2	2	3	3	3
20	3	4	4	5	5	6
30	5	5	6	7	8	9
40	6	7	8	9	10	12
50	7	9	10	12	13	14
60	9	10	12	14	15	17
70	10	12	14	16	18	20
80	12	14	16	18	20	23

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90	13	15	18	20	23	25
100	14	17	20	23	25	28
120	17	20	24	27	30	34
160	23	27	32	36	40	45

As already mentioned, when the train will stop depends not only on the driver and his response but also on the brakes and brake delay time. Brake delay time (for air brakes) for "P" type is usually between 3 and 6 seconds and for "G" type between 18 and 30 seconds [14]. Values of distances traveled by train during brake delay time for P and G types are shown in Table III (P) and Table IV (G).

TABLE III
VALUES OF DISTANCES TRAVELLED BY TRAIN DURING BRAKE DELAY TIME FOR "P" TYPE

v \ t_{bd}	3	4	5	6
10	9	12	14	17
20	17	23	28	34
30	25	34	42	50
40	34	45	56	67
50	42	56	70	84
60	50	67	84	100
70	59	78	98	117
80	67	89	112	134
90	75	100	125	150
100	84	112	139	167
120	100	134	167	200
160	134	178	233	267

TABLE IV
VALUES OF DISTANCES TRAVELLED BY TRAIN DURING BRAKE DELAY TIME FOR "G" TYPE

v \ t_{bd}	18	20	22	24	26	28	30
10	50	56	62	67	73	78	84
20	100	112	123	134	145	156	167
30	150	167	184	200	217	234	250
40	200	223	245	267	289	312	334
50	250	278	306	334	362	389	417
60	300	334	367	400	434	467	500
70	350	389	428	467	506	545	584
80	400	445	489	534	578	623	667
90	450	500	550	600	650	700	750
100	500	556	612	667	723	778	834
120	600	667	734	800	867	934	1000
160	800	889	978	1067	1156	1245	1334

Reaction distance can be simply calculated by summing values from Table II and Table III (or IV). It's important to mention that input data for reaction distance calculations (except movement speed) is empirical.

The difficult part in train stopping distance determination is the calculation of train braking distance. More precise results require more input factors that affect braking. In this paper, several equations for the determination of train braking distance are presented. The first model is given in Eq. (3) [3], [10]:

$$l_{bd} = \frac{v^2}{2 \cdot (a + g \cdot \tan\alpha)} [m] \tag{3}$$

where:

- a is deceleration provided by the braking system,
- g is gravitational acceleration,
- α is the angle of the gradient.

Next model is Maison's formula, given in Eq. (4) [15]:
for freight trains (*v<70 km/h*):

$$l_{bd} = \frac{4.24 \cdot v^2}{10^3 \cdot \varphi \cdot p_k + 0.0006 \cdot v^2 + 3 - i} [m] \tag{4}$$

where:

- φ is friction coefficient depending on gradient (for $i < 15‰ \Rightarrow \varphi = 0.10; i > 15‰ \Rightarrow \varphi = 0.10 \div 0.00133$),
- i is gradient,
- p_k is braking percentage.

Pedeluck's empirical model for passenger trains (*v=70÷140 km/h*) is shown in Eq. (5) [15]:

$$l_{bd} = \frac{\varphi \cdot v^2}{1.093 \cdot p_k + 0.127 - 0.235 \cdot i \cdot \varphi} [m] \tag{5}$$

Minden models for passenger and freight trains are presented in Eq. (6) and Eq. (7) [15]:
for passenger trains:

$$l_{bd} = \frac{3.85 \cdot v^2}{\left[6.1 \cdot \psi \cdot \left(1 + \frac{p_k}{10}\right)\right] + i} [m] \tag{6}$$

for freight trains:

$$l_{bd} = \frac{3.85 \cdot v^2}{5.1 \cdot \psi \cdot \sqrt{p_k - 5} + i} [m] \tag{7}$$

where:

- ψ is the parameter which values are between $0.5 \div 1.25$ (concerning the brake type characteristics).

In eastern literature and researches, Method PTR is generally recommended. The total braking distance can be calculated as shown in Eq. (8) [19], [22]:

$$l_{bd} = \sum_{q=1}^{n} \frac{4.17 \cdot \left({v^2}_p - {v^2}_k\right)}{b_T + w_{ok} + i} [m] \tag{8}$$

where:

- n is the number of q intervals,
- v_p, v_k are initial and final movement speed in q interval,
- b_T is specific braking force,
- w_{ok} is specific main movement resistance.

Variation of the previous model is shown in Eq. (9) [20]:

$$l_{bd} = \sum_{q=1}^{n} \frac{500 \cdot ({v^2}_p - {v^2}_k)}{(b_T + w_{ok} + i) \cdot \theta} [m] \qquad (9)$$

where:

- θ deceleration provided by specific deceleration force $(107 \div 120)$.

The last model presented in this paper is shown in Eq. (10) [4]:

$$l_{bd} = \frac{4.13 \cdot v^2}{\mu \cdot \delta \cdot p_k + w_{ok} + i} [m] \qquad (10)$$

where:

- μ is friction coefficient on the contact area between the train wheel and the brake pad,
- δ is pressure coefficient (can be calculated as the ratio of the specific braking force per braking pad and braked mass per braked axle [4]).

III. Overlap

Overlap is defined as the length of track in advance of a "stop" signal, that must be clear. The main purpose of the overlap is to provide additional safety in case the train overruns a "stop" signal by a short distance due to any reason related to braking [6] or track condition. There're are two types of overlaps (Fig. 1): block overlap (BOL) and signal overlap (SOL).

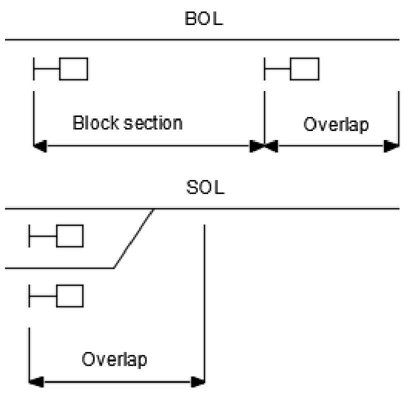

Fig. 1. Overlap

On lines with short block sections, an entire block section could be used as an overlap [6].

On Republika Srpska Railways, the overlap is needed when the train has movement authority (except when passing the station without stopping). In [9] is stated that block overlap on Republika Srpska Railways must be at least 50 meters long. Signal overlap, when used on the dead-end track, needs to be at least 100 meters long [8]. In normal conditions, overlap length should be between 100 and 200 meters, but no longer than 300 meters [8]. On special occasions, because of traffic circumstances, it can be shorter than 100 meters, but not less than 50 meters (there's an exception in block overlap where it can be shorter than 50 meters if line gradient after block signal is greater than 6 ‰, and speed isn't greater than 90 km/h) [8].

HŽ Infrastructure (Croatian infrastructure manager) recommends the length of the signal overlap to be 100 meters at the home signal when there isn't a shunt limit, and 50 meters if there're limits of shunt [2]. At the exit signal, signal overlap needs to be 100 meters long [2]. Block overlap is recommended to be at least 50 meters long (there is the same exception as on Republika Srpska Railways where it can be shorter than 50 meters if gradient and speed conditions are met) [2].

On German railways home and block signal overlap (called Durchrutschweg or D-Weg) is recommended to be between 100 and 200 meters depending on the point that needs to be protected and 50 meters for block signals that are only used for train separation with block length not shorter than 950 meters [5]. Behind exit signals, 200 meters is recommended for speed exceeding 60 km/h, 100 meters for speed not exceeding 60 km/h and 50 meters for speed not exceeding 40 km/h [5].

On Austrian railways, overlap (Schutzweg) behind main signals (entry/home, exit, block, etc.) is recommended to be 50 meters, or in special cases, due to physical space constraints, it can be 25 meters [1].

Overlap length on Russian railways (Защитный участок) needs to be at least long as the length of the braking distance provided by ALS (automatic locomotive signalling) emergency braking [21].

On NSW railways (in Australia), 300 meters is the minimum recommended for speed less than 60 km/h, 400 meters for speed between 60 and 80 km/h, and 500 meters for speed exceeding 80 km/h [12].

Generally, overlap length determination should be influenced by the following factors [7], [12]:

- historical precedents and experimental data,
- maximum line speed,
- permanent speed restrictions,
- train approach speed,
- emergency braking curves,
- gradient,
- train protection system,
- sight distance,
- weather conditions (where significant),
- physical space constraints (in stations).

IV. Influence on Railway Traffic Safety

Traffic safety should be the number one priority in all traffic systems. While managing traffic safety, the main rule that should be followed is that only improvement or maintenance of the current safety level is acceptable. Anything other than that shouldn't be allowed (reduction of traffic safety for cost reduction sake). Quantitatively, the traffic safety level is represented by the number of traffic accidents and levels of injuries. However, in some cases, it isn't recommended (or possible) to quantitatively determine the level of traffic safety due to a lack of relevant data or data in general. In this paper qualitative approach is used to provide some aspects of influences on railway traffic safety by train stopping distance and overlap.

Railway traffic is known for high-level safety compared to road traffic since railway traffic is using a predetermined path - a rail track. A predetermined path is an advantage when it comes to traffic safety, but it's also a shortcoming when it comes to mobility. Maintaining a high level of safety produces high costs, especially when it comes to infrastructure design and maintenance. One more reason why railway traffic has a high safety level is the usage of train movement authority. The train can move through the station or on an open line only if it has movement authority which can be granted only when there're no other trains, objects, or obstacles on the path.

Train stopping distance is the factor that greatly influences railway traffic safety. For trains to safely travel on railway, trains must be provided with sufficient distance in which to stop [3]. It's possible to classify two types of stopping distances. For railway systems, it's important to predetermine values of maximum stopping distances because they're used when designing certain parts of the system (for example block sections or overlaps). As already said, stopping distance length is affected by reaction and braking distances. When it comes to reaction distance, driver reaction distance is the factor that on first-hand doesn't seem to have a great influence on overall value, but if we take the worst possible outcome from Table II, for reaction time 1 second, the train travels almost 30 meters (for 100 km/h speed). If we take into account that this time is empirical and that in certain cases it can be longer, for example, if this time is 4 seconds (for same speed), driver reaction distance is over 100 meters. To keep this time as low as possible it's important for drivers to have full attention while driving. General conditions for drivers that should contribute to shorter reaction distances are: [11]:

- physical and mental requirements,
- appropriate education,
- appropriate training under qualified supervision for driving,
- possession of a professional license,
- possession of a driving license,
- possession of additional specific certificates.

Quality and comprehensive periodical control of physical and mental health greatly help in traffic safety maintenance. The brake delay time is part of reaction distance that isn't correlated to the human factor. It depends on the train brake system, train composition, and train type (passenger or freight) [4]. This time is also measured empirically. It depends on the time required for pressure increasement up to 95 % in brake cylinders and the breakthrough speed of the command execution [4], [14]. It's important to mention that this paper considerers only air brakes that are used on Republika Srpska Railways. Regular control and maintenance of brake systems should keep this time within its boundaries and with that, it'll undoubtedly provide shorter brake delay distances. The second part of the stopping distance, braking distance has the main influence on train stops. As already shown in the models presented, all formulas are empirical. It's impossible to calculate braking distance without uncertainties. Besides human and brake system factors, the braking distance is affected and by some external factors, like main movement resistance force, gradient, and friction. For braking distance determination, especially for higher speeds and advance systems, simplified models shouldn't be used for calculations [4]. When rail and road vehicles (or pedestrians, cyclists, etc.) collides on (or outside of) level crossings stopping distance comes to the fore. Even if they are prescribed in advance, in the court of law, question, if the train could stop before the collision, is often. When it comes to level crossings, by BiH legislative, rail vehicles have right of way when encountering other vehicles (no matter from which side other vehicles are approaching the railroad), unless otherwise is specified by the sign [18]. This is confirmed by the Republika Srpska railway traffic safety act, where is stated that the train has right of way regarding other non-rail traffic units [17]. In [17] is also stated that pedestrians and cyclists are allowed to cross railroad only on level crossings. Knowing the previous article, if a collision occurs on an open rail line, outside of level crossing, there shouldn't be room for guilty of train drivers, regardless of the stopping distances, if they met all other railway traffic safety conditions (stated in [11], [13], [17]), especially if we take into account that on an open rail line, between stations, the train uses maximum speed allowed. On level crossings with the lowest level protection, "stop" signs are installed before the railroad, meant for road traffic users, who by themselves warn that stopping before the railroad is necessary. In most cases, when a collision occurs, the sight distance between rail and road units is too short for a train to stop. In addition to sight distances being too short, often physical obstacles, terrain configuration, rail line position, and adverse weather conditions further extend stopping distances. When designing block sections, each block length needs to be a minimum length as the longest stopping distance on that line.

Overlap is a component which length partially depends on stopping distance, but mainly on speed and gradient. Longer overlaps provide a higher level of safety but they take highly more infrastructure capacity. On block sections, they're used for authority granting to the next train (Fig.2.).

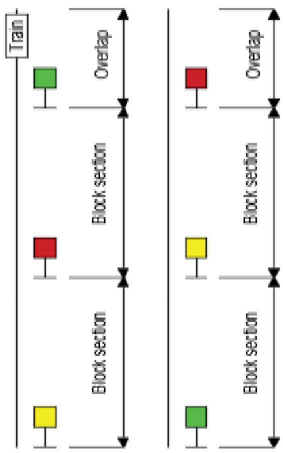

Fig. 2. Authority granting by overlap

Their length is important but it's not that significant for railway traffic safety as train stopping distance. It's important to provide a certain length behind the signal to contribute to greater traffic safety. The overlap length shouldn't be less than 50 meters, or longer than 500 meters, as all different railways proposed in their technical guides.

V. Conclusion

Railway traffic is a complex technical and technological system, which safety is influenced by many factors.

Maintaining railway traffic safety on a high level produces high costs and greater capacity consumption. In the example of train stopping distances, shorter distances are more desirable, while in the case of overlaps, longer ones are preferable.

Train stopping distance has a great influence on railway traffic safety because it depends on three variables: human, internal (technical), and external (resistances). There're many ways and models for calculating this distance, but neither of them can provide 100 % accuracy. To access more precise results, it's required to use more advanced models which consider more factors.

In case of overlap, length can be also calculated using mathematical models, but it's preferable to use practices of other railways, and historical precedents, and experimental data. Besides the safety aspect, the overlap has a great influence on capacity.

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