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PRELIMINARY STUDY OF SHAPING THE RAILWAY TRACK GEOMETRY IN TERMS OF THEIR MAINTENANCE COSTS AND CAPACITY

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Abstract:

In Poland, due to the increase in investments made by railways in recent years, and thus the increase in the replacement value of transport infrastructure, the need for expenditure on infrastructure maintenance will increase in the next 30 years, or the development of the developed transport network will degrade. As part of the overall discipline of resource management, subdiscipline has emerged - infrastructure asset management. As part of the management of railway transport infrastructure, the demand for cheaper maintenance costs will grow. The cost reduction of infrastructure maintenance is possible through meticulous assessment of its condition, rational selection of locations and scope of repairs at the assumed risk level, as well as at the stage of preparation of new construction or modernization projects taking into account aspects of later maintenance. For some time, we have been observing the accumulation of knowledge (methods, programs, procedures) in the country and abroad enabling optimization of infrastructure condition assessment and programming of its maintenance. The implementation of these solutions may result in a more rational use of funds for infrastructure maintenance and not disturb its smooth functioning in operation. The article discusses aspects that should be considered in the design process of railway infrastructure. Particular attention was paid to the durability of steel components of the railway superstructure, maintenance costs as well as aspects related to the capacity of the track node. An example of dependence of selected values of radial arcs depending on their durability and maintenance costs was presented. It was proposed to change the track layout at the Warszawa Srodmiescie passenger stop planned for reconstruction. Calculations of kinematic parameters for various configurations of railway turnouts were performed. Also, calculations of the capacity for the existing track system solution as well as the proposed track system after reconstruction of the analysed Warszawa Srodmiescie railway station were also carried out.

Keywords: *railway infrastructure, maintenance cost, capacity, rail durability*

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1. Introduction

In Poland, due to the increase in investments made by railways in recent years, and thus the increase in the replacement value of transport infrastructure, the need for expenditure on infrastructure maintenance will increase in the next 30 years, or the development of the developed transport network will degrade.

As part of the overall discipline of resource management, subdiscipline has emerged - infrastructure asset management. It is a set of rules, methods and tools necessary for rational management of assets put into infrastructure (Heller 2016). It includes railroad infrastructure management. As part of the management of railway transport infrastructure, the demand for cheaper maintenance costs will grow. The cost reduction of infrastructure maintenance is possible through meticulous assessment of its condition, rational selection of locations and scope of repairs at the assumed risk level, as well as at the stage of preparation of new construction or modernization projects taking into account aspects of later maintenance. This requires, among others taking and disseminating following methods:

- use of tools supporting design,
- optimization of structural solutions for railway infrastructure elements,
- recognition of the technical condition of the infrastructure,
- dissemination of theoretical applications that allow an objective determination of the technical wear of the infrastructure,
- technical condition forecasting and repair planning (including computer decision support),
- ensuring the quality and durability of infrastructure repairs,
- economical and reliable determination of repair costs,
- ordering repair works in time,
- certification of materials and works performed.

For some time, we have been observing the accumulation of knowledge (methods, programs, procedures) in the country and abroad enabling optimization of infrastructure condition assessment and programming of its maintenance (Jacyna et al. 2018), (Jacyna and Wasiak 2015). The implementation of these solutions may result in a more rational use of funds for infrastructure maintenance and not disturb its smooth functioning in operation.

An important element in the proper functioning of the elements of railway transport infrastructure in large urban centres and agglomerations is the optimization (minimization) of its maintenance costs, as well as striving to maximize its capacity. The best example of the load on the railway infrastructure is the Warsaw Railway Junction (WRJ), including the diametrical line. The Warsaw Railway Junction is one of the most important elements of railway infrastructure, both in Poland and in Europe. It plays an important role in long-distance (domestic and international) and local communication - both in passenger and freight transport. Its special location because at the intersection of International Transport Corridors makes it strategic. Combined with the service of a very densely inhabited area of the Warsaw agglomeration, it creates very large, diverse and intersecting transport flows, requiring proper and efficient traffic organization on individual railway lines converging at the node. Preparation of appropriate interchange and transhipment infrastructure is also important, as conceptual and construction works are carried out by the PKP PLK Infrastructure Manager.

The importance of WRJ in this diametrical line is evidenced by the fact that in 2017, according to the UTK report (UTK 2019), as many as 3 stations and one passenger stop lying on the diametrical line were in the group of 10 most loaded stations in Poland. In 2017, the Warszawa Srodmiescie stop served 29,4 million passengers, which means 477 trains a day.

It becomes common to evaluate structures (including transport structures) by analysing the cost of their entire 'life cycle', e.g. rail roads (Marx and Fry 2010) shown in Figure 1. It can be considered as mapping the 'life cycle' for infrastructure in general. Attention should be paid to high maintenance costs (understood as ongoing efficiency and periodic recovery of used infrastructure). The costs of ongoing efficiency assurance and restoration of used infrastructure within 30 years can reach a level of 50-60 percent of the original value, which means that expenditure on infrastructure maintenance should be annually 1,6-2,0 percent of the infrastructure replacement value (it is estimated that the reconstruction of road infrastructure in the European Union amounts to over 8 billion EUR), while the actual expenditure in these countries has never exceeded 1 percent. This results in a progressive decapitalization of road infrastructure (it is even worse with railways) (EFR 2014).

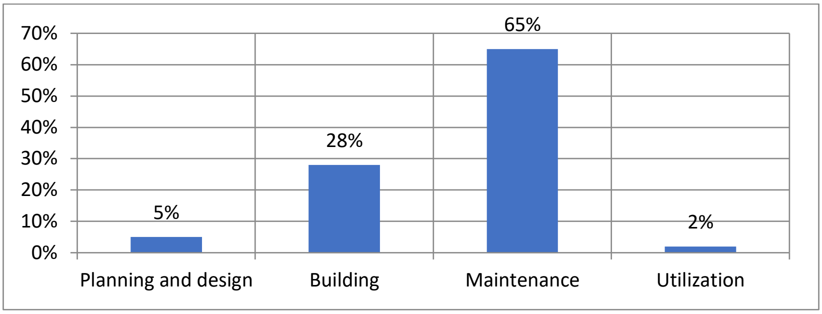

Fig. 1. Percentage of costs of individual elements making up the "life cycle" of railways
Source: own study based on (Marx and Fry 2010)

Also, in the aspect of modernization and reconstruction of railway junctions and station or line track infrastructure facilities, it is worth considering the possibilities of reducing maintenance costs as well as increasing the capacity of its capacity.

The aim of the article is to analyse how to shape the railway track geometry in terms of their maintenance costs and capacity.

2. Literature review

The most important value for railway traffic is its safe and secure, efficient (Jacyna-Gołda et al. 2017) and reliability (Jacyna and Żak 2016). This security depends on many aspects (Burdzik et al. 2017): from the state of infrastructure (Jacyna and Kłodawski 2011), (Kukulski et al. 2019b), (Lesiak et al. 2015), (Sysyn et al. 2018), superstructure (Domin et al. 2016), (Kukulski and Kardas-Cinal 2020), (Szkoda et al. 2019), as well as from the appropriate organization of rail traffic (Jacyna et al. 2017), (Jacyna et al. 2019), (Jacyna at al. 2016), (Jacyna and Krześniak 2018), (Jacyna-Gołda et al. 2014), (Urbaniak et al. 2019) and the way of conducting traffic on the railway line (Albrecht et al. 2013), (Gołębiowski et al. 2019), (Jacyna et al. 2019), (Kukulski et al. 2019a), (Toruń et al. 2019). Therefore, audits (Bartoś and Gołębiowski 2019) or appropriate analysis of data from recorders (Jacyna et al. 2018), should be carried out in order to detect irregularities in a timely manner and be able to repair them instead of leading to tragedy - e.g. by modernization (Sharma et al. 2017). However, the repair option will depend on the amount of resources needed to carry it out (Liden and Joborn 2016). It should be noted that not only in railway transport, safety plays a very important role - it is the same, among others in air transport (for example: Zieja et al. 2015, Kowalski et al., 2016) or road transport (for example: Niculescu et al., 2018).

One of the methods to delay repair is the introduction of train speed limits on individual sections of railway lines (Sobota et al. 2018). This is a temporary measure to raise funds for a specific repair. This results in longer train travel times and an increase in the dissatisfaction of passengers or customers in the freight transport process (Bartoś and Gołębiowski 2019). This can be limited by, among others by using vehicles with better starting characteristics. When planning repairs, the appropriate thermal regime should also be taken into account (Izvolt et al. 2018). When considering the problems of shaping the railway network, energy aspects should also be taken into account - both from the point of view of supplying energy to vehicles (Szeląg and Patoka 2014), and from the point of view of supplying the equipment necessary to secure traffic (Feng et al. 2017). The problem of early detection of objects (obstacles) located in the track area is also important (Sacchi and Regazzoni 2000).

Based on the above considerations, the following conclusion can be drawn when designing the shape of railway transport infrastructure, account should be taken of its maintenance costs, capacity and other aspects. In the scientific literature, it is difficult to find positions that would take up such topics related to railway infrastructure in the aspect of its maintenance. However, we can find selected scientific positions that relate to selected elements of the railway infrastructure - including the geometry of the railway line, open line capacity or the durability of the railroad structure. Optimization tools for railway line geometry elements including transition curves are also presented (Zboiński and Woźnica 2015). The considerations are theoretical. However, they can also be one of the elements in minimizing the costs of maintaining rail infrastructure in railway arches.

Another case of consideration when designing track geometrical systems for durability is publication (Bałuch 1983). The authors present here aspects related to the essence of design due to durability, including anticipated changes in operation as well as the impact of these changes on durability. An important element discussed in this publication is the selection of radii and bevels for railway turnouts, taking into account the durability of the railway surface. These are important issues because these elements of the railway pavement in operation are exposed to rapid wear and affect the capacity of the station system or railway route.

The second thematic area concerning the capacity of the open lines or station track systems was undertaken, among others in publications (Armstrong and Preston 2017), (Gasparik and Cempirek 2019), (Karoń and Firlejczyk 2006), (Landex et al. 2008), (Rotoli et al. 2016), (Rychlewski 2009). Research topics include analytical considerations and the use of ready-made applications, e.g. microsimulation models used in RailSys or OpenTrack programs (Kosicki et al. 2015). In article (Grulkowski et al. 2017) railway traffic was analysed based on two parameters: train capacity and deceleration. The influence of diversified railway structure on railway capacity is presented. In the article (Rychlewski 2009) the impact of modernization of railway lines on their capacity was assessed, aspects of collision of track systems and the concept of reconstruction of turnout roads were taken into account.

3. Analyses - case studies

3.1. General assumptions

Designing new or modernizing existing railway infrastructure once took place in a "classic" way, i.e. it represented traditional principles of designing both linear and point facilities. Design documentation in the form of analytical calculations and a set of drawings were made using the AutoCAD program or earlier also manually. Design support programs that appeared a few years ago, aim to improve designing (support designing), and not to replace the designer completely. Therefore, the designer is constantly required to have knowledge of the art and design principles that are extremely important in the profession of designer. There are many application solutions that are used in professional design. In addition to knowledge of design principles and the use of design-supporting tools, it should also be necessary to consider aspects of the subsequent maintenance of these objects as well as their functionality. Both aspects the maintenance system and the functionality of the used solutions can affect lower operating costs as well as greater capacity of the route or station track node. Optimization analysis can be carried out with a selection of max radius of arches or appropriate selection of the type of turnout to suit the needs of the movement.

3.2. Analysis due to the durability of rail elements

The value of radii of arches or slants of railway turnouts is important for their durability, especially when a significant part of the traffic takes place on a lateral direction, this is the case, among others, at railway stations or technical and holding stations serving the railway undertakings' fleet in terms of maintenance. The current practice of determining arc radii in lateral direction when constructing new lines or modernization was based on certain catalogue schemes specified in standards dedicated to some railway lines or feasibility studies (Bałuch 1983). The lateral wear of rails in arches with small radii is very intense, therefore they should be limited at the design stage, and in operation by using special lubricants reducing friction. This also has its drawbacks, as the grease is transferred to the wheel of a railway vehicle and in extreme cases reduces the friction coefficient between the wheel and rail also on a straight section, it can also affect track circuits. The function describing the wear of rails in arches was developed on the basis of many years of observation and experimental research (Bałuch 1983) and takes the form:

$$\lambda_s = -5,75 \cdot 10^{-7} \cdot R^2 + 1,62 \cdot 10^{-3} \cdot R - 0,15 \qquad (1)$$

where:
R – adopted arc radius [m],
λ_s – function correcting rail durability in arches.

Based on the above dependencies, a graphic form describing the rail durability depending on the radius of the arc can be developed (Fig. 2).

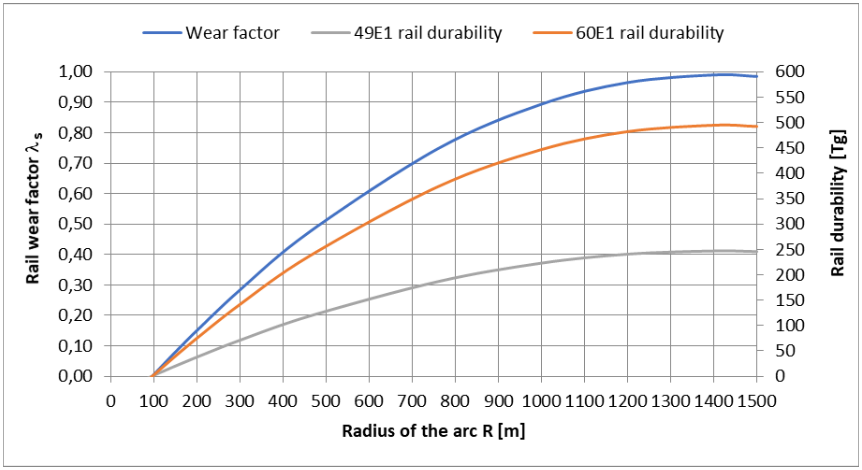

Fig. 2. Graphic form describing the durability of the rail depending on the radius of the arch

The curves for different rail types shown in Fig. 2 present how the radius of the arc in which the rails are located affects their durability. The value of rail wear coefficient should be treated as a characteristic of reducing the durability of the entire structure.

Assuming the standard 190 and 300 m turnout radii, it can be read that the durability of 60E1 rails will be respectively 69 and 142 Tg. For 49E1 rails it will be 34 and 71 Tg being half the life of the 60E1 heavy rail. Therefore, it is necessary to strive to maximize the value of the radius of arches in the lateral tracks of turnouts. The exception may be the track systems of the Technical and Holding Station (THS), where due to the limited surface area there is no technical possibility to use such a solution (Fig. 3).

The figure above shows the radii of lateral arches enabling the train to enter the holding and repair hall. The difference in the radius of the arc results from the geometry and layout of the tracks enabling the way to service facilities, limited significantly by the accessibility of the terrain. However, the restrictions on the minimum arc radius for this type of vehicle *R* = 60 m have been respected.

Fig. 4 and 5 and an exemplary arrangement of the station head of the current (fig. 4) and planned for reconstruction of the Warszawa Srodmiescie stop from a two-track to a four-track point. This is the author's concept, because according to the infrastructure manager's assumptions and plans, the passenger stop is to be rebuilt into a four-track station. Track layout was proposed taking into account the maximum turnout radii and an additional double trapezoidal variant. Such a system will allow in the event of traffic difficulties to lead traffic on the non-basic track to bypass an obstacle (e.g. damaged rolling stock).

In the further part of the article, calculations of kinematic parameters (point 3.3) as well as capacity (point 3.4) were made in comparison to the existing state (fig. 4) and concept of the new station (fig. 5).

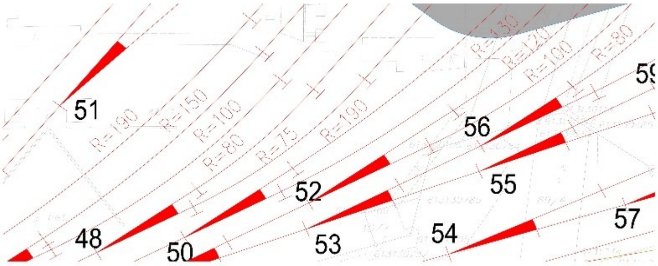

Fig. 3. An example of a turnout head design on an example of THS

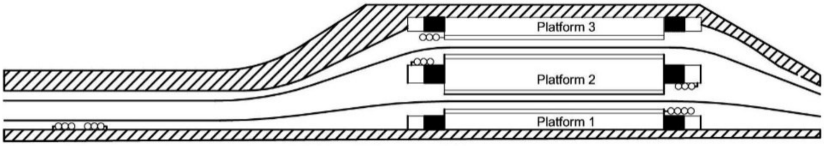

Fig. 4. Current tracks and platforms arrangement at the Warszawa Srodmiescie stop

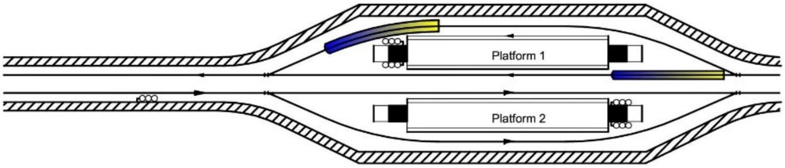

Fig. 5. Concept of track and platform arrangement at the Warszawa Srodmiescie station

3.3. Analysis due to kinematic parameters

The minimum radius of the horizontal arc, whether on the open line or in a turnout head, should also result from the optimization of the geometrical system while maintaining boundary conditions. This is important if the determinant is the maximum speed on the open line affecting the capacity of the entire line or its sections. Acceptable kinematic parameters on Polish railway lines have been identifier, among others in the Id-1 document (PKP PLK S.A. 2015) prepared by the PKP PLK infrastructure manager.

The kinematic parameters of the unbalanced lateral acceleration a_d and the acceleration increase Ψ were calculated from the formulas (2) and (3):

$$a_d = \frac{V_{max}^2}{R \cdot 3,6^2} \left[\frac{m}{s^2}\right] \tag{2}$$

$$\Psi = \frac{V_{max}^3}{R \cdot 3,6^3 \cdot b} \left[\frac{m}{s^3}\right] \tag{3}$$

where:
R – adopted arc radius [m],
V_{max} – maximum train speed [km/h],
b – rigid base of the wagon taken as 20 [m].

Table 2 presents the calculated kinematic parameters for the new track system of the Warszawa Srodmiescie station track head.

Table 2. Calculated kinematic parameters

	No.		
	1	2	3
Adopted radius of the arc of lateral track in turnout R [m]	300	500	760
V_{max} [km/h] on lateral track	40 (50)	60	80
Unbalanced lateral acceleration a_d [m/s^2]	0,411 (0,643)	0,555	0,649
Acceleration increase Ψ [m/s^3]	0,228 (0,446)	0,463	0,722
Theoretical durability of rails 49E1 / 60E1 [Tg]	71/142	129/258	187/375

3.4. Analysis due to maintenance costs

The selection of the minimum radius of the circular arc can affect the cost of the entire pavement. Determining the approximate factor increasing the expenditure on maintaining the railway surface depending on the arc radius used can be read from Fig. 6 (Bałuch 1983). The assumptions assume that the expenditure on maintaining a straight track is equal to $w = 1$.

Based on the graph, you can see what value of the factor increasing the expenditure on maintaining the track located in a circular arc should be taken depending on the radius of the circular arc used on the open line or in the turnout head. Of course, these are theoretical assumptions, because each infrastructure manager has its own maintenance policy and probably has precise data on the costs actually incurred for the repair and maintenance of railway infrastructure, including track.

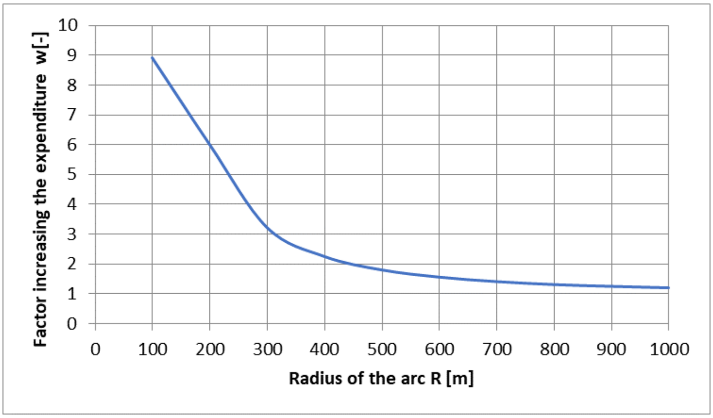

Fig. 6. Curve showing the factor increasing the expenditure on maintaining the surface in the arch
Source: own study based on (Bałuch 1983)

Decisions on carrying out infrastructure repairs and its maintenance should be made based on diagnostic measurements and ongoing observations, taking into account the assessed parameters, among others: synthetic track condition indicator, horizontal, vertical unevenness, and wear of surface elements.

Therefore, in the design process of track geometrical systems and track connections, the maximum radius values obtainable under existing limitations should be used. This approach will extend the life of the rail infrastructure and partially reduce the number of repairs.

3.5. Analysis due to capacity

Low capacity is also often due to point speed restrictions: on crossings, engineering objects, switches, used railway traffic control devices, additional track additions, etc. Reconstruction of track systems is an investment that requires significant financial outlays. The first stage on the way to improving capacity may be the modernization of traffic control devices, use of modern passenger trains with a high acceleration of start up to 1,2 m/s^2, large proportion of the door surface (at least 25% in relation to the length of the vehicle) with a width of at least 1,2 m. An important element in rolling stock to support agglomeration is the floor height at the same level as the platform. However, this is still a serious problem until the reconstruction of platform heights to one height standard of 760 mm or 550 mm for regional stations and passenger stops. All these activities can allow for faster exchange of travellers at the passenger stop or railway station, thus reducing the time taken by the train to take the platform edge.

The capacity of a new or modernized system can be calculated in an analytical manner or with the use of specialized computer applications, e.g. using microsimulation tools (Open Track, RailSys). For example, the capacity of the Warszawa Srodmiescie passenger stop in its present shape was calculated as well as for the reconstruction proposal (Figures 4 and 5).

3.5.1. Capacity analysis for the existing state (according to Fig. 4)

Assumptions for calculations:

- maximum speed on the open line is 60 km/h (PKP PLK S.A. 2019a),
- braking distance for a maximum speed less than or equal to 60 km/h is 400 m (PKP PLK S.A. 2019b),
- four-aspect automatic line block system on the open line are installed, which means that the first distance after the entry semaphore to the starting operating control point of the open line for the opposite direction and the last distance (before the entry semaphore to the operating control point ending the open line) must be equal to the braking distance, while the remaining distances must have a length at least half the braking distance - for the

analysed example it is min. 200 m (PKP PLK S.A. 2019c),

- for calculations, it was assumed that a typical trainset running on the line is a vehicle EN57AKM series with a length of about 65 m (Koleje Mazowieckie 2019), for which acceleration of start-up and deceleration during braking is equal to 0,9 m/s^2 (average value for vehicles containing apparatus of MEDCOM company) (Biliński et al. 2009),
- it was assumed that a typical trainset composition is 3 EN57AKM (maximum composition), so the length of one composition is about 195 m (which is close to the length of one distance equal to half of the braking distance.

The following relationship to calculate the capacity *N* of the Warszawa Srodmiescie passenger stop was used:

$$N = (1-\varphi)\frac{1440-(T_n+T_s)}{t_{zw}} \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{4}$$

where:
φ – traffic flow rate, $\varphi = 0{,}3$ (Nowosielski 1999),
T_n – track node occupation time per day related to passing non-basic trains and shunting being the sum of the products of the number of non-basic trains and shunting and occupation times of the track node occupation by these rides:

$$T_n = l_{pn}\cdot t_{pn} + l_{pm}\cdot t_{pm} \quad [\text{min}] \tag{5}$$

where:
l_{pn} – number of non-basic trains [1],
t_{pn} – occupation time of the track node by non-basic train [min],
l_{pm} – number of shunting rides [1],
t_{pm} – occupation time of the track node by shunting ride [min],
T_s – free time at work of the examined track node during the day caused by the implementation of converging routes being the product of the number of converging routes and the converging routes implementation time:

$$T_s = l_{ps}\cdot t_{ps} \quad [\text{min}] \tag{6}$$

where:
l_{ps} – number of converging routes [1],
t_{ps} – implementation time of converging route [min],
t_{zw} – average time of occupation of a track node by one basic train [min].

Substituting formulas (5) and (6) to formula (4) we get the following form of the formula for calculating the capacity of a track node *N*:

$$N = (1-\varphi)\frac{1440-\begin{pmatrix} l_{pn}\cdot t_{pn} + \\ l_{pm}\cdot t_{pm} + \\ l_{ps}\cdot t_{ps} \end{pmatrix}}{t_{zw}} \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{7}$$

where: signs as in formulas (4), (5) and (6).

Let us calculate the capacity for the Warszawa Srodmiescie passenger stop for the current situation. It was assumed that due to the specificity of the line, no non-essential train traffic or shunting operations occur. So l_{pn} and l_{pm} is equal to 0. Due to the fact that we analyse the capacity of a passenger stop, there is also no such thing as a converging route. Therefore, l_{ps} is also equal to 0. Formula (7) therefore takes the following form:

$$N = (1-\varphi)\frac{1440}{t_{zw}} \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{8}$$

where: signs as in formula (4).

To be able to calculate the capacity, we need to calculate the occupancy time of the track node. In the minimal version it will be time consisting of three components:

$$t_{zw} = t_{wj} + t_p + t_{zo} \quad [\text{min}] \tag{9}$$

where:
t_{wj} – time of train entering the entire length into the distance at which the platform is located [min],
t_p – passenger exchange time [min],
t_{zo} – time when the distance at which the platform is located is released by the train [min].

Train entry time was calculated using train motion kinematics - this is the assumption made for the purposes of this article. The braking time from 60 km/h to 0 km/h will last 18,52 s and it will take place on the road 154,35 m. Due to the fact that the distance is 200 m and the trainset composition length is 195 m, it means that we still need to calculate the occupation time of the section with a length of 240,65 m, which the train will overcome at a speed of 60 km/h – 14,44 s. So t_{wj} will be equal to 32,96 s. Taking into account various factors (including device reliability), it is assumed that this time will be assumed at t_{wj} = 40 s. Passenger exchange time for the Warszawa Srodmiescie passenger stop, railway undertakings accept at t_p = 90 s. The last factor is the time when the distance is released, which should be calculated for the length of the adopted trainset composition. Therefore, the first element is the acceleration of the train for 18,52 s on the road 154,35 m. We must add the time of uniform motion at 60 km/h on the route 40,65 m, which is equal to 2,44 s. So t_{zo} = 20,96 s. Taking into account various factors (including reliability of devices) it is assumed that this time will be adopted for t_{zo} = 25 s. Substituting the above data into formula (6) we get:

$$t_{zw} = 40 + 90 + 25[\mathrm{s}] = 155\mathrm{s} \approx 2{,}58\mathrm{min} \tag{10}$$

Substituting the value obtained in the calculation (10) to the formula (8) we get:

$$\begin{aligned} N &= (1-0{,}3)\frac{1440}{2{,}58} = 0{,}7 \cdot 558{,}14 = \\ &= 390{,}698 \approx 390 \quad \left[\frac{\text{trains}}{\text{day}}\right] \end{aligned} \tag{11}$$

Thus, the "ideal" capacity of the analysed passenger stop, which does not ensure an adequate level of traffic flow, is equal to 390 trains per day. In accordance with the principles of railway traffic organization (Jacyna et al. 2019) train traffic should be conduct on the so-called "green light". This means that in the case of a four-aspect automatic line block system, the next train should have three free block distances in front of it. This causes that t_{wj} = 60 s. Therefore t_{zo} = 175 s ≈ 2,92 min. Real capacity is equal to:

$$\begin{aligned} N &= (1-0{,}3)\frac{1440}{2{,}92} = 0{,}7 \cdot 493{,}15 = \\ &= 345{,}205 \approx 345 \quad \left[\frac{\text{trains}}{\text{day}}\right] \end{aligned} \tag{12}$$

Please note, that the above calculations are made for a passenger stop (track node). The capacity of the railway line passing through this stop, which will determine the final number of trains that will pass through this expedition point, has not been calculated.

3.5.2. Capacity analysis for the designed state (according to Fig. 5)

Assumptions for calculations:

- maximum speed on the open line is 60 km/h (PKP PLK S.A. 2019a),
- braking distance for a maximum speed less than or equal to 60 km/h is 400 m (PKP PLK S.A. 2019b),
- distance between the exit semaphore and the dangerous place when a passing train has entered the lateral direction is min 50 m (PKP PLK S.A. 2019b),
- distance between the exit semaphore and the dangerous place when a passing train has entered the straight ahead direction is max 120 m (PKP PLK S.A. 2019b) – 100 m was taken for calculations,
- four-aspect automatic line block system on the open line are installed, which means that the first distance after the entry semaphore to the starting operating control point of the open line for the opposite direction and the last distance (before the entry semaphore to the operating control point ending the open line) must be equal to the braking distance, while the remaining distances must have a length at least half the braking distance - for the analysed example it is min. 200 m (PKP PLK S.A. 2019b),
- for calculations, it was assumed that a typical trainset running on the line is a vehicle EN57AKM series with a length of about 65 m (Koleje Mazowieckie 2019), for which acceleration of start-up and deceleration during braking is equal to 0,9 m/s^2 (average value for vehicles containing apparatus of MEDCOM company) (Biliński et al. 2009),
- it was assumed that a typical trainset composition is 3 EN57AKM (maximum composition), so the

length of one composition is about 195 m (which is close to the length of one distance equal to half of the braking distance,
- it was assumed that the turnouts have a 1:9 slant and a 300 m radius; therefore, rides in a lateral direction at a speed of 40 km/h.

Analysing formula (7), it can be determined that we do not deal with the movement of non-basic trains and shunting rides. Thus, l_{pn} and l_{pm} is equal to 0. We are dealing with converging routes at the time of departure. It is not possible to carry out outgoing rides at the same time. Therefore, in this situation, the formula for calculating the capacity will be as follows:

$$N = (1-\varphi)\frac{1440-(l_{ps}\cdot t_{ps})}{t_{zw}} \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{13}$$

where: signs as in formulas (4) and (6).

There are two unknowns in the meter. The first is the number of converging routes l_{ps}, while the second is the duration of the converging routes t_{ps}. The number of converging routes l_{ps} will be equal to half the number of trains that can be handled in the current (existing) system shown in Fig. 3 - formula (12) i.e. $l_{ps} = 345:2 = 172{,}5 \approx 173$ routes.
When it comes to the time of implementation of the converging route t_{ps} we have two types of rides to consider: ride with velocity 40 km/h (driving from a lateral direction) and ride with 60 km/h (driving from a straight direction). The calculation should specify the average duration of the converging routes. So, it can be expressed by the following formula:

$$t_{ps} = \frac{t_{zw}^{40}+t_{zw}^{60}}{2} \quad [\text{min}] \tag{14}$$

where:
t_{zw}^{60} – time at which the track node is occupied by the train leaving at speed 60 km/h [min],
t_{zw}^{40} – time at which the track node is occupied by the train leaving at speed 40 km/h [min].

Now specify the node's occupancy time – t_{zw}. As mentioned in the description of formula (4) - node occupancy time is average. Therefore, the calculation will take the same form as the calculation of the converging routes time - formula (14). So, let's calculate the node's occupancy time for two cases:

for driving at a speed of 60 km/h – t_{zw}^{60}:
in this case, we need to calculate the time needed to overcome the full braking distance (400 m) by the train accelerating from 0 km/h to 60 km/h. The acceleration time from 0 km/h to 60 km/h lasts 18,52 s and will take place over a distance of 154,35 m. Next, the train rides with uniform motion over a distance of 245,65 m increased by a length of 195 m – 440,65 m. The time needed to overcome this section is equal to 26,43 s. Thus, the entire time of slowing down the distance is equal to 44,95 s. Considering the additional time 50 s was adopted. So $t_{zw}^{60} = 50$ s.

for driving at a speed of 40 km/h – t_{zw}^{40}:
in this case, we need to calculate the time needed to overcome the full braking distance (400 m) by the train accelerating from 0 km/h to 60 km/h, while a certain section of the road is overcame at speed 40 km/h. The road to overcome at this speed is about 200 m + 195 m of length of the trainset – in total 395 m. The acceleration time from 0 km/h to 40 km/h lasts 12,33 s and will take place on the section with length 68,41 m. Next, the train travels in a uniform motion on the section with length 326,59 m. The time it takes to overcome this section is 29,4 s. The remaining distance is 5 m + length of the trainset 195 m – in total 200 m. In the first phase, we have increased speed from 40 km/h to 60 km/h, which will take 6,17 s and this will take place on the road 17,08 m. There is 182,92 m to overcome at a speed of 60 km/h in 10,97 s. Therefore, the entire deceleration time is 58,87 s. Taking into account the additional time, it was assumed 65 s. So $t_{zw}^{40} = 65$ s.

Now we can start calculating the duration of the implementation time of converging route using formula (14):

$$t_{ps} = \frac{65+50}{2}[\text{s}] = 57{,}5\text{s} = 0{,}96\text{min} \tag{15}$$

In addition, it was assumed that $t_{ps} = t_{zw} = 0{,}96$ min.

Having the above data, it is possible to calculate the capacity of the Warszawa Srodmiescie station using the formula (16):

$$N = (1-0,3)\frac{1440-(173\cdot 0,96)}{0,96} = \\ = 928,9 \approx 928 \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{16}$$

Thus, the "ideal" capacity of the analysed passenger stop, which does not ensure an adequate level of traffic flow, is equal to 928 trains per day. In accordance with the principles of railway traffic organization (Jacyna et al. 2019) train traffic should be conduct on the so-called "green light". This means that in the case of a four-aspect automatic line block system, the next train should have three free block distances in front of it. This causes that $t_{ps} = t_{zw} = 77{,}5$ s $\approx 1{,}29$ min. Real capacity is equal to:

$$N = (1-0,3)\frac{1440-(173\cdot 1,29)}{1,29} = \\ = 660,3 \approx 660 \quad \left[\frac{\text{trains}}{\text{day}}\right] \tag{17}$$

Please note, that the above calculations are made for a station (track node). The capacity of the railway line passing through this station, which will determine the final number of trains that will pass through this expedition post, has not been calculated.

4. Summary

The issues presented in the article discuss important elements that should be taken into account when designing or rebuilding station and line track infrastructure. The analysis took into account aspects of durability, maintenance costs as well as technical parameters related to design. The article also includes the capacity aspect that affects the functionality of the line or point railway infrastructure.

Analyses related to the selection of radii of circular arches show that one should strive for the maximum value of this radius not only on the open line but mainly in track systems of stations or passenger stops. By using this solution, we gain a longer life cycle (inter-repair cycle). For example, using an arc radius of $R = 300$ m instead of $R = 200$ m, we gain more than a double extension of rail life. This will be important in the case of large railway stations, or technical and holding stations, where dozens of turnouts will often be built, and then maximizing the lateral tracks radius can significantly reduce their maintenance costs.

The arc radius is also important from the point of view of kinematic parameters and the comfort of the train passing through this curvature. This affects the maximum train speed at turnouts. This is important when increasing the capacity of a line or station. The larger radius of the lateral track allows faster descent from the main track to the secondary track, allowing the next train to enter. This is important on heavily loaded railway junctions, such as the Warsaw Railway Junction mentioned in the article. The presented capacity calculations for station track systems with different types of turnouts and arc radii used show that we can achieve a higher capacity of almost 1,4 times. To gain a comprehensive improvement in the quality of service in the railway area, it is necessary to take into account various factors and elements not only of the track system and its geometry, but also minimize maintenance costs at the design or reconstruction stage.

The analyses are preliminary assumptions for the development of tools supporting the assessment of design solutions, among others in terms of capacity, durability, maintenance costs of track infrastructure or due to technical requirements.

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