Igor Gisterek
dr inż.
Politechnika Wrocławska
Wydział Budownictwa Lądowego i Wodnego
Katedra Mostów i Kolei
igor.gisterek@pwr.edu.pl

DOI: 10.35117/A_ENG_17_07_02

Matching the platform edge placement to rolling stock in existing tram systems on the example of Wroclaw

Abstract: The work contributes to the development of the optimal solution of the horizontal and vertical gap between the platform edge and the tramway threshold in Wroclaw. General arguments for the development of urban rail transport have been described, and the basic features of an attractive system are discussed. Historical and current works focused on the position of the car floor with relation to the platform were collected, taking into account selected current foreign regulations. Suggested solutions possible for use in Wroclaw conditions were posed. The necessity of carrying out further detailed studies and considerations to be carried out in the second part of the work has been emphasized.

Keywords: Urban transport; Tramway; Platform; Tramway stop

Introduction

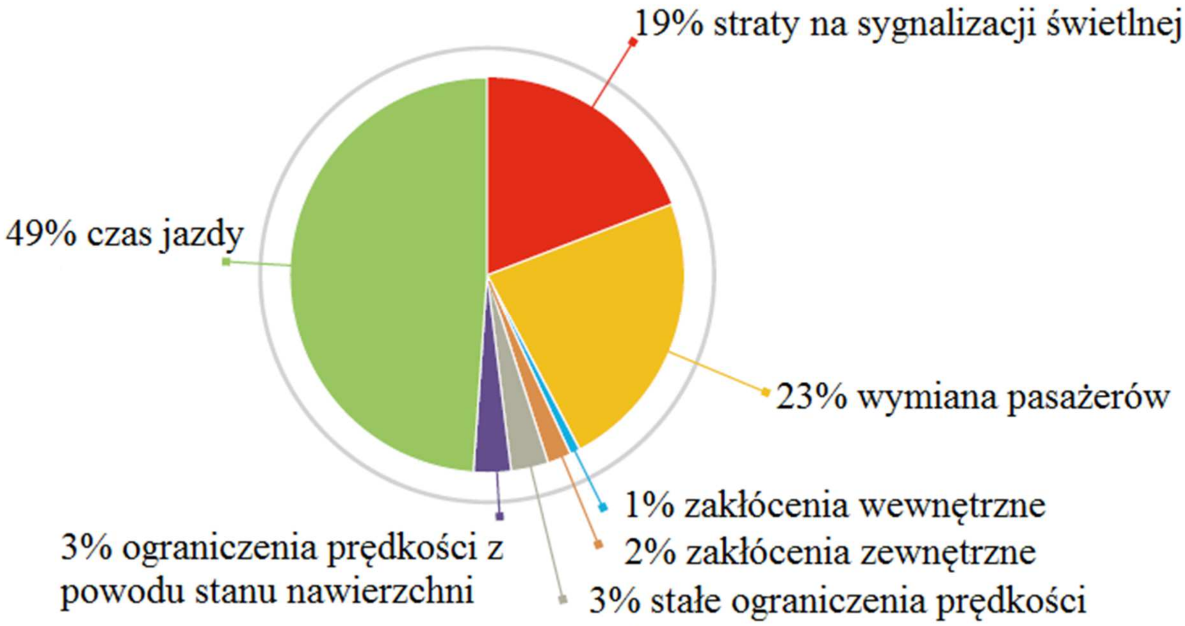
Due to the significant costs of construction and maintenance of transport infrastructure as well as the purchase and operation of vehicles, more and more emphasis is placed on their effective use. Especially with investments co-financed from EU funds, one of the basic parameters is their efficiency, i.e. the internal rate of return on investment, which is calculated taking into account the expected number of passengers. It is observed that railway carriers record a relatively stable situation in this area, expressed at best in single-digit growth. For example, according to UTK [13], the increase in the number of rail passengers was 4.3% in 2016, but with a 9.9% increase in transport performance. Meanwhile, the fundamental increase in the mobility of the society is continued with the help of individual motorization. On the example of Wrocław, the number of passenger cars registered per 1000 inhabitants shows a continuous upward trend, growing in the years 2005-2015 from 384 to 600 [17]. This testifies to the implementation of increased mobility of the society mainly through the use of cars. Only the analysis of foreign examples shows where the real potential of public transport is hidden: while all railways in Poland carried around 292 million passengers in 2016, the same Berlin S-Bahn system was used in 2015 by almost 417 million travelers [7]. If Polish cities are to follow in the same direction, it will be necessary to shift the center of gravity of rail transports from occasional trips, carried out sporadically over long distances, to everyday commutes carried out to implement basic living issues: work, study, fulfillment of life needs and recreation.

The type of rail transport dedicated to daily transport are e.g. trams. The investments in the development and repair of infrastructure observed in recent years, as well as the replacement or modernization of public transport rolling stock, do not always bring the desired effects, often resulting in a slight increase in the number of passengers. The background of this phenomenon is multi-faceted and complex, in addition, strongly dependent on local conditions. However, you can try to bring them to the common denominator, determined by the degree of attractiveness of public transport. The inflow of passengers begins when the overall attractiveness of rail transport exceeds the total quality of the other means of movement. Among the basic components of the attractiveness of public transport can be mentioned:

- driving time, identified with the speed of movement,
- regularity of driving, as the interval between successive courses,
- frequency of running, also as a criterion for assessing efficiency,
- punctuality of driving as a quantitative and qualitative indicator,
- convenience of connections connected with the traffic truss,
- traveling comfort: heating, ventilation, easy access to the vehicle,
- driving safety,
- information about the course of the line and system, inside vehicles and at bus stops,
- service culture - employee behavior [8, 14].

Many of these criteria are difficult to measure, and the recognition of a particular parameter as attractive is subject to individual user assessment. It can safely be assumed that the continuous improvement of such key parameters as travel time, line coverage and punctuality have a significant impact on the frequency of transport in public transport as long as it allows to keep these factors at least at a competitive level for car transport. The subtlety of sustainable transport in cities also means that often facilitating one means of communication involves intentional or incidental difficulties for other road users. For example, assigning high priority to trams in traffic lights may spoil the green wave effect for cars, but also the opening of a new street that brings traffic to the center increases the inflow of cars and will block public transport where it has not previously taken place.

Considering the various components of the attractiveness of the means of transport, it should be noted that each of the above items consists of a whole host of features, conditions and dependencies, often interrelated, sometimes contradictory. To achieve an improvement, you can take multi-faceted activities, or you can concentrate on individual components, for example by increasing the commercial speed. An analysis of the existing state, shown in the example of Dresden in Fig. **1**, indicates that approximately half of the total driving time falls on the vehicle's movement, a quarter is the time of passenger exchange, and the last quarter are the obstacles and obstacles in traffic, for which the lion's share corresponds to the loss of time resulting from waiting for a signal to allow driving. From this you can conclude that the biggest profit will be achieved by improving one of three key shares: clean driving time, passenger exchange or waiting for a signal. The tram traffic speed in the city is a resultant of the top speed limit on the route sections and nodes, the placement of stops along the route and rational accelerations at the start-up and braking of the vehicle, so the reasonably planned maneuvering network is rather small here. In turn, raising the priority for trams to the absolute or full level is not always possible, especially where important transport routes cross, which is relatively frequent in the center area. Of course, this is based on the assumption that the tram is already a partially privileged participant in the traffic; in Poland, even in new realizations, you cannot always accept such an assumption automatically.



1. Components of the total tram driving time (Dresden, 2012), for [2]

The Dresden example is not entirely reliable in Polish conditions. Since 1993, tracks have been intensively rebuilt and modernized there, so sections in poor technical condition are getting shorter and less frequent. The rolling stock structure also exceeds the quality with national examples: the city's DVB rolling stock consists of almost 170 low-floor wagons, and less than 20 Tatra cars, similar to the Konstal 105N tram. On this basis, it should be assumed that in Polish cities the combined shares of time losses taking place with the expectation of a permissive signal, passenger exchange, and speeding driving dominate over the time of "clean" driving, providing significant opportunities to improve the state of affairs. This will translate into a number of positive phenomena, which include:

- increasing attendance in public transport vehicles, i.e. more favorable traffic structure (modal split),
- reducing operating costs by faster passenger exchange, shorter timetables, shorter stops,
- increasing the commercial speed, but not at the expense of other road users,
- removing physical barriers for people with reduced mobility,
- improving the safety and comfort of all passengers.

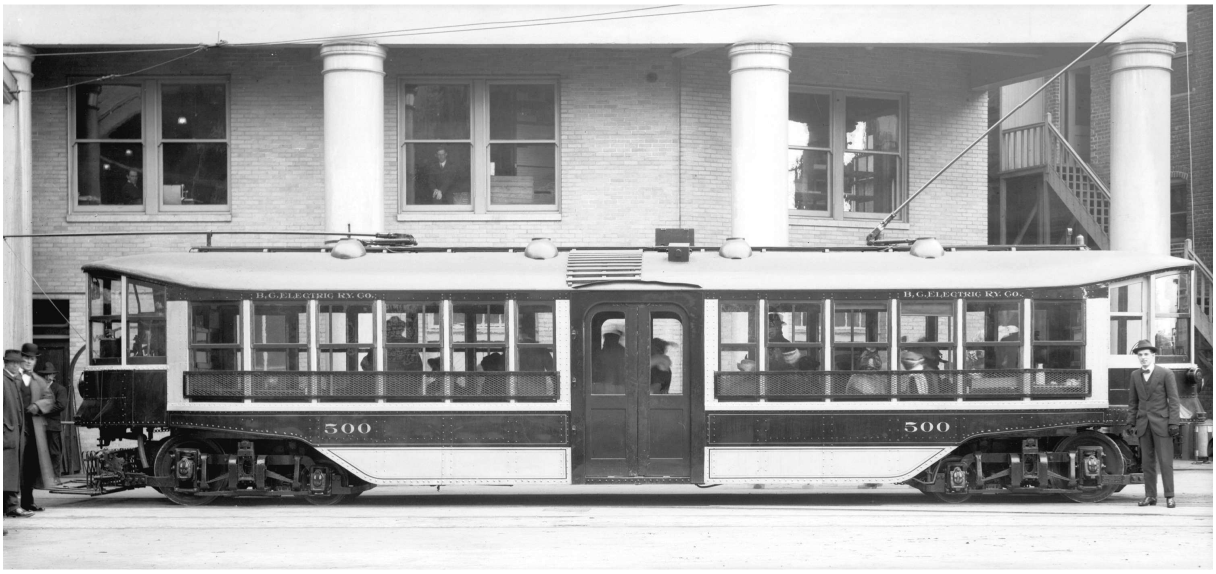
One of the ways to increase the attractiveness of tram transport may be the acceleration of passenger exchange, implemented by mutual approaching the platform edge and the vehicle's threshold. The historical and current conditions of this factor are described below.

Selected historical solutions

From the very beginning of passenger rail transport, there was a dogma proclaiming that the floor of the vehicle runs over the highest point of its wheels. By the way, under the box, there was room for the majority of electrical equipment and other devices. This often led to the formation of rather curious structures, as in Fig. **2**.

2. Electric tram with extremely high floor, approx. 1895 (public domain) [6]

This state of affairs was not particularly troublesome in the early years of tram systems, and for a long time in smaller towns. The relatively low intensity of traffic and the small capacity of the wagons did not cause any significant disturbances in maintaining the timetable. Real problems began in the last decade of the nineteenth century when in larger cities the tram traffic became so intense that it was necessary to take appropriate countermeasures. The tried-and-tested solutions included, among other things, the use of a trailer, lengthening of wagons (including the first attempts to build multi-compartment cars), increasing the speed of travel, extending inter-adjacency intervals. At the same time, it was noticed that significant losses of time are caused by the exchange of passengers at stops and the related system of selling tickets to people on board. In addition to transferring ticket sales to the interior of the car, two attempts were made to solve the problem: by building high platforms tailored to the vehicle floor, which was virtually impossible in the case of a classic streetcar in mixed traffic, and by lowering the floor in vehicles, which it became real already at the beginning of the 20th century with a reduction in the size of electric motors and the use of Maximum trolleys (Fig. **3**).



3. Low-floor tram from Brill, Vancouver, approx. 1910 [3]

In spite of the relatively dynamic development of such constructions, their shortcomings quickly emerged, which could not be removed with the then state of the art. These vehicles were not suitable for routes with significant longitudinal slopes, because they were practically unable to overcome the vertical curves of the track, while the centrally placed doors were relatively narrow and thus impeded the flow of passengers, or significantly weakened the structure of the car causing its deformation and cracking. Therefore, apart from the episode of the "Montos" carriage in the 1930s, low-floor constructions were again developed only at the end of the 1980s.

The much more popular solution were high-floor tram cars, based on the assumptions of the PCC wagon, being developed in the US since the mid-1930s. From that moment, the first wagon door installation on the slant of the box in front of the front trolley is also dated. While in the conditions of spacious streets and wide boxes of American cars, the slope was of aesthetic significance, the transplantation of the PCC scheme to European conditions resulted in strongly narrowing bridges. This is the direct cause of the current drawback, which is the threat of security getting on from the high tram platforms - even with a very good adjustment of the edge to the width of the car, the width of the slit in the diagonal increases rapidly.

Despite significant progress and introduction of numerous features present in trams until today, PCC cars also had their drawbacks. These included the height of the first stage, i.e. the difference between the plane of the railheads and the threshold level of the vehicle. Even in the railroad cars, which have been used up to this day, this issue has not been adequately resolved: in a disadvantageous situation, eg when getting on the level of a paved road with a significant transverse slope, the first level exceeds 50cm, which is a barrier for all people with reduced mobility. An indirect solution to this problem, which is used both in earlier high-floor trams as well as modern low-floor trams, is an additional step spread or extended from the threshold.

Current solutions

The solutions currently used for the best possible adjustment of the platform edge to the vehicle threshold can be divided into two main groups: fixed devices (including periodically controlled ones) and mobile ones. The former are inherently less technically complicated, while they require maintaining a high stability of the track's position relative to the platform and limiting the permissible tolerances of the vertical and lateral wear of rails, rolling stock wheels and other clearances. The second group, due to its cost, technical complexity and the necessity to spend on ongoing maintenance, should be quantified to a definite minority. These realizations are numerously dominated by the steps being extended or deposited from the vehicle when the door is opened, but there are also devices installed on the platform, closing the horizontal gap or lifting a fragment of the platform surface to the vehicle door height [5]. Regardless of the choice of a particular solution, the purpose of their application is to significantly increase the level of safety and comfort of boarders, but some reserve must be kept resulting from the unreasonably repetitive trajectory of vehicle movement in the track. An indisputable issue is the necessity of such tolerance, while its numerical value is debatable. Infrastructure managers and carriers postulate the maintenance of a vertical and horizontal gap of approximately 100mm, taking into account the simultaneous occurrence of all possible adverse circumstances and limiting of wear, i.e. wear of rails, rims, suspension deflection, platform icing, deformation of the edge and track deformation. It should be clearly emphasized that such a wide margin of operational negligence is incompatible with any standards providing access to mass transport for people with reduced mobility. Implementing regulations for the most liberal law in this matter, the Swiss law called BehiG [1], assume acceptable values of horizontal and vertical gaps of 50 and 50 or 70 and 30 mm, respectively. An important difference is a context: in French tram networks, the dimensions of gaps are even smaller, because in principle, without exception, these systems are built anew, while the Swiss tram stops are overwhelmingly modernized [4, 10, 15, 16]. In one of the pioneering works from almost 20 years ago [10], the above issue has been described in some detail. The author clearly states that the use of a 50mm gap is optimal and successfully used in a metro, SKM, and quick tram systems. It also mentions two reasons why it should not be used in the case of a classic tram. The first - it can lead to blocking doors that would hang too low above the platform. The second - in the case of platforms located on the arch at each door, and at straight platforms - at the door placed diagonally at the beginning or end of the vehicle, the size of the horizontal gap increases to dangerous values, even 25-30cm [10]. Since then, the industry has found satisfactory and effective solutions to the above problems, used extensively in the case of new implementations. The problem of door leaves sliding over the platform was solved in two ways: either the door slides over a relatively wide threshold of the vehicle, at no time hanging above the platform surface, or the main door panels end about 25cm above the platform floor, and the remaining part of the door is closed by a degree that, in a vertical position, complements the plane of the door, while at a standstill it rotates to a level and thus closes the horizontal gap, as in Fig. **4**.

4. A door with a movable step used in Zurich, photo by Andrew Nash (fragment)

The problem of oblique positioning of the car box fragments in relation to the platform and the associated excessive horizontal gap is solved by locating where possible stops at straight sections of the track, even at the expense of changing their current location, and thus placing the door on the length of the vehicle so that it always falls on side of the car. In maintaining a small vertical gap, compensating for the effects of a wheel, rail or vehicle load, a large number of passengers are assisted by automatic floor height adjustment systems, already used even in domestic production trams [12]. As already indicated, these solutions are effective and easily applicable to new investments. The issue becomes much more complex when modernizing existing tram networks, especially those where different types of wagons have different width of the box in its lower part and different height of thresholds. The next part describes the proposal to solve this problem on the example of Wrocław trams.

Proposal for a solution for Wroclaw

The tram rolling stock of MPK Wrocław consists of 362 cars of various types, the oldest of which were produced in 1975, and the latest in 2015 [18]. In terms of types, this figure is as follows: PESA 2010NW carriages - 8 items, Skoda 19T - 31 items, Skoda 16T - 17 items, Moderus Beta - 6 items, Protram 205 - 26 items, Protram 204 - 12 items (6 trains), Konstal 105Na and derivatives - 264 items (132 trains), a total of 225 trains. In terms of external dimensions and division into parts, 6 different types of vehicles should be considered, since Skoda 16T and 19T do not differ in this respect. Direct age analysis of vehicles can lead to the following conclusions: if you want to immediately withdraw from service the 40 and older wagons, in 2017 34 new warehouses would have to be provided, for the 35-year old trains it would be 74 warehouses, while taking thirty years of operation it would be necessary urgent purchase of as many as 106 warehouses with a uniform length of around 30m. However, the above list does not take into account the significant fact that the majority (168 items) of 105Na vehicles have been modernized by Protram since 2005 so that their lifetime has been extended further. However, it should be expected that even these should be replaced with newer cars until around 2025. This raises the need to purchase a large lot of new trams (around 130 items) in the next decade. This assumption does not take into account the

Wrocław network development plans presented in the Wrocław Tramw Program [9], which will increase the demand for at least a dozen new vehicles, so the total number of new wagons needed may reach or even exceed 150 units.

Due to the fact that in the near future there should be an exchange of around half of MPK's rolling stock, common purchasing guidelines should be developed and implemented, which will determine the desired technical parameters of new wagons, regardless of the contractor. These guidelines must also take into account the unification of the external dimensions of the vehicle, including the number and arrangement of doors on the length of the car, the height of the threshold or the distance from the threshold of the track axis. The introduction of such common requirements will make it possible to ensure that all new trams are compatible with a newly built and modernized infrastructure adapted to the needs of passengers with reduced mobility, regardless of whether the deliveries will come from different manufacturers or not. These guidelines must take into account the possibility of a long period of using relatively new wagons already owned by MPK, since their operation may end even after 2050. This is based on the fact that currently, the reason why today's trams are completely or almost completely low-floor they are to be replaced with more perfect constructions, so in the light of today's state of the art one should expect their use as long as possible.

The analysis of orders for new trams proves that in developed countries there are definitely 100% low-floor constructions, but there are also vehicles with about 2/3 of the low floor while maintaining the deployment of all double-leaf doors along its length. The vehicle is then functionally divided in such a way that the zone for passengers traveling at a short distance includes relatively fewer seats and more standing, especially near the door, while travelers traveling longer is dedicated to the area in the area of the raised floor, but with a large number of seats. The standard solution, common to these two types of cars, is the box width of 2.40 or 2.65 m and the height of the vehicle threshold 300 mm above the surface of the railheads. Today's Wrocław trams planned for further long-term operation include four types of wagons: Skoda (16T and 19T), Protram 205WrAs, Moderus Beta and PESA 2010NW. For the above types in Table **1**, a combination of two basic parameters was made when designing parameter platforms: horizontal distance from the straight track axis to the car's threshold described as semi-width and vehicle threshold height. Due to the partial lack of access to the manufacturer's data, they relied on their own measurement with an accuracy of 1 cm. Trams with different heights of entries were given the lowest. For comparison, the parameters of the Konstal 105Na tram were also entered in the table.

Tab. 1. Widths and heights at the threshold of Wrocław tram carriages

Ordinal number	Wagon type	Half-width [cm]	Height [cm]
1	Konstal 105Na	112	43
2	Protram 205WrAs	117	38
3	Moderus Beta	117	35
4	Skoda 16T i 19T	120	35
5	PESA 2010NW	120	35

The data presented in the table show that the height of thresholds in Wrocław trams does not take values lower than 35cm above pgs (the plane of railheads), while the widest trams reach 120cm semi-width from the track axis. The above values were compared with the proposal presented by MPK Wrocław, in which the platform edge is 1285mm from the track axis and 270mm above pgs. The comparison shows that the vertical difference between the platform and the threshold in the nominal state (new rolling stock, platform, track) can reach even 11cm, while the horizontal - almost 12cm, which significantly exceeds the values contained in [1]. This problem can be solved in the following ways: moving the platform closer to the track and lifting it, introducing modifications to the rolling stock, or applying both solutions at the same time. Of course, there are boundary conditions limiting the selection possibilities: the distance of the platform from the track axis is limited by the width of the widest streetcar of 1200mm, and the height of the lowest vehicle threshold of 350mm, with safety margins. Proposals for solutions from this are presented below:

a) Platform with dimensions of 1285/270, no modification in the existing rolling stock. The adoption of this solution means that the passenger exchange takes place in more favorable conditions than on any existing platform in Wrocław, but the service of disabled passengers without disassembly of the ramp is still not ensured (Figure 5). The future rolling stock should be better adapted to the platform by lowering the nominal entry edge to 300mm above pgs, using the floor height maintenance system in the 270-300mm range and mounting the thresholds reducing the horizontal gap to 45mm, while maintaining the box half-width of 1200mm.

5. Skoda 19T with a spreading ramp near the platform 1285 / 270mm

b) Platform with dimensions of 1285/300, modifications to the existing rolling stock. In the 204WrAs and Beta wagons, a low-floor swing-and-turn door is used in the low-floor member, which makes the panels pass several cms above the platform during opening and closing (the rubber gasket sealing the bottom edge of the door goes below the threshold). In practice, it would turn out that platforms 300mm and higher already with low wheel wear and loading of the vehicle make it impossible to open the door. This problem can be easily solved with the assumption that the door in the low floor section can be replaced by a sliding door. The remaining tramway doors are suspended about 8cm higher, so they are not a problem. The horizontal gap in all types of wagons should be reduced to 45mm by re-mounting the thresholds. In existing cars, it will be necessary to increase maintenance costs caused by the need to maintain the reduction of the threshold in operation in the range of 0-5 cm. An example of a tram door equipped with thresholds is shown in Fig. 6. Service of passengers with limited mobility will be possible in Skoda and PESA wagons, difficult in the Protram and Moderus cars. The rolling stock came with a semi-width as in a) and a nominal height of 330mm, with a floor height maintenance system in the 300-330mm range.

6. Skoda Forcity Plus streetcar doors equipped with a threshold

c) Platform with dimensions of 1285/320, modifications to the existing rolling stock. To reduce the horizontal gap to the value of approximately 45mm, the above-described thresholds should be installed. Despite a good height adjustment, the problem with the existing rolling stock is the lack of a floor height system - the margin for lowering the threshold due to deflection of the suspension together with the wear of the wheel rims is only 30mm, with the now reduced wheel radius due to 40mm rim wear, which will increase maintenance over a reasonable measure. It will also be necessary to check the value of the offset of the open sliding-sliding doors from the side of the car. Trams must be installed on all trams to achieve the effect described in b). The rolling stock came in half-width as in a) and the nominal height of 350mm (identical with the PESA and Skoda cars), with the floor height maintenance system in the 320-350mm range.

d) Platform with dimensions of 1245/270, no modification in the existing rolling stock. This solution reduces the horizontal gap to a value below 5cm for wider (Skoda, PESA) and about 8cm for narrower (Protram, Moderus), so it does not enforce the installation of thresholds on the majority of the existing rolling stock. Unfortunately, due to different heights of thresholds in carts, either it leaves a large value of the vertical gap, or interferes with the space intended for the movement of the door panels. The margin of error is also reduced, so it should be used here to solve the problem of "softening" the edge of the platform, e.g. in the form of rubber caps and, optionally, slip strips on wagons. It is recommended to choose the future rolling stock with half-width 1200mm, nominal height 300mm, with the floor height maintenance system in the range of 270 - 300mm.

e) Platform with dimensions of 1245/300, no modification in the existing rolling stock. The problem described in c) expands to all existing low-floor wagons, despite the use of sliding-sliding doors in PESA and Skoda. Difficulties and operational limitations associated with the need to ensure adequate inventory related to the opening of doors above the platform make this solution not to be further analyzed.

Regardless of the choice of one of the above solutions, it is possible to increase the margin of operating stock by moving the fixed elements of the platform further away from the track axis, while the approximation of moving parts, adjustable or flexible, as described in detail in [5]. It is also possible to postulate other horizontal and vertical distances, however, with operated wagons with different widths and heights, no solution will provide the minimum, uniform gap sizes for all types of trams.

Summary

This article is only an introduction to the scope of the issues to be addressed when adapting the existing tram system to the introduction of a stepless solution for the replacement of passengers. Further considerations, including the possibility of expanding the wagon box over the platform, solutions for tram and bus platforms, multi-criteria analysis and final conclusions will be presented in the next part of the publication.

Source materials

[1] Bundesgesetz über die Beseitigung von Benachteiligungen von Menschen mit Behinderungen (Behindertengleichstellungsgesetz, BehiG) vom 13. Dezember 2002 (Stand am 1. Januar 2017).

[2] Damit Bahn und Bus pünktlich sind. Broszura DVB Dresden, 2013.

[3] Elsner H.: The Hedley-Doyle stepless streetcar. 80 years ahead of its time. N.J. International, 1997.

[4] Faivre C., Alauzet A., Marin – Lamellet C.: Etude portant sur les difficultés de franchissement des lacunes quai-seuil par les usagers de fauteuil roulant lors de l'accès aux transports guides. INRETS (Institut National de Recherche sur les Transports et leur Sécurité), 2009.

[5] Gisterek I.: Innowacyjne konstrukcje krawędzi peronowych, materiały konferencji Nowoczesne Technologie i Systemy Zarządzania w Kolejnictwie, 2013.

[6] http://snippetsfromthedust.blogspot.com/2014/09/ive-been-working-on-railroad.html.

[7] http://www.s-bahn-berlin.de/unternehmen/firmenprofil/kurzfassung.htm, dostęp 02.2017.

[8] Jurczak M.: Integracja i konkurencja jako sposoby kształtowania publicznego transportu zbiorowego na przykładzie aglomeracji poznańskiej. Rozprawa doktorska, Uniwersytet Ekonomiczny w Poznaniu, 2013.

[9] Kruszyna M. et al.: Wrocławski Program Tramwajowy, 2016.

[10] Makuch J.: "Właściwe kształtowanie krawędzi przystanków tramwajowych w świetle sukcesywnego wprowadzania taboru niskopodłogowego w miastach polskich", XIII Konferencja Naukowa: Pojazdy Szynowe 98.

[11] Materiały Tisseo SMTC z dn. 21.09.2007.

[12] Moderus Gamma - po latach jest (informacja prasowa), InfoTram.pl, data dostępu 18.11.2016 http://inforail.pl/moderus-gamma-po-latach-jest_more_89189.html.

[13] Powrót pasażerów. Najlepszy rok od 2008. Rynek Kolejowy, UTK, 27.01.2017.

[14] Rejmoniak A.: Kryteria sprawności działania systemu komunikacji miejskiej, Transport Miejski nr 12/85.

[15] Rozporządzenie Republiki Francuskiej: Arrêté du 13 juillet 2009 relatif à la mise en accessibilité des véhicules de transport public guidé urbain aux personnes handicapées et à mobilité réduite. NOR: DEVT0912618A.

[16] Stadtbahnen in Deutschland. Verband Deutscher Verkehrsunternehmen (VDV), Bundesministerium für Verkehr, Bau- und Wohnungswesen. VDV, 2000.

[17] Studium uwarunkowań i kierunków zagospodarowania przestrzennego Wrocławia - polityka zrównoważonej mobilności. Materiały UM Wrocław, 07.02.2017.

[18] Wykaz tramwajów MPK Wrocław, stan na 26.02.2016, data dostępu 23.02.2017.