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Transportation Research Procedia 14 (2016) 1977 – 1986

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Proposal of methodology for calculating the quantity of validation machines in railway transport

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Abstract

The transport process is a summary of time and substantive processes that make up the transport chain. The requirement of relocation exists at the beginning of each transport process in passenger transport. Finding the appropriate connection, familiarity with the transport conditions, the purchase of travel documents and their subsequent validation are other activities involving the transport process. One form of validation can be ensured by the responsible employees of the carrier. The second form is a creation of self-service system on the track section. Economic matters of carrier points to disadvantages of validation the travel documents by train crew in comparison to the tracks where is implemented the self-service system. Paper analyzes the possibilities of validation machine placement for the validation of travel documents, which can be placed at railway stations and stops or in vehicles in low demand areas of railway transport. The paper analyzes the factors that affect the required quantity of validation machines at the railway stations and stops or in railway vehicles, depending on the parameters of railway infrastructure (number of tracks, maximum track speed, number of railway stations and stops on the track and their average mutual distance), railway vehicle fleet (construction of the vehicles, number of doors, transport capacity) and transport technology (time of train sets circulation, transport distance, travel speed, creating timetable). Based on the analysis of these factors paper provides the methodology for calculating the quantity of validation machines in railway transport. The methodology is applied to the model.

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: calculation; railway passenger transport; self-service system; validation machines

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.165

1. Introduction

The transport system is a set of activities, which passenger transport is performed by Knizka et al. (2009) and Gasparik (2010). At the beginning of passenger transport process is required the need of relocation. As the second it is important to become familiar with transport regulations, to find suitable connection, to buy required transport ticket and validate it.

One form of transport ticket validation is to ensure an empowered employee by the carrier. Other form of transport ticket validation can be creating and building up the self-service system (Gogola, 2015). This system is well known from the urban public transport.

The disadvantage of transport ticket validation by carrier's employee (usually conductor) is according Nedeliakova et al. (2013) and Camaj and Dolinayova (2011) that the system requires the higher staff costs in comparison with the self-service system that puts responsibility of transport ticket validation on passenger (using marking machine itself).

Nomenclature

α_r, α_z	margin to start and stop [h]
j	number of railway tracks [track]
K_D	coefficient of doors [-]
k_{TT}	travel time utilization index [-]
L	length of line section [km]
L_i	travelled distance [km]
$n_i^{\emptyset vm}$	average number of validation machines for one platform/underpass in i-th railway station
N_d	number of doors in wagon [door.wagon^{-1}]
N_m	number of needed validation machines [machine]
N_m^{min}	minimal number of needed validation machines [machine]
N_i^p	number of platforms/underpasses in i-th railway station [platform]
N_j^s	number of railway stops with j railway tracks (if one separate platform is by every track) [stop]
N_{seat_i}	amount of passenger seats [seat]
$N_{seat.km}$	transport performance [seat.km]
N_{tr_i}	amount of trains [train]
$N_{train.km}$	conveying performance [train.km]
$N_{train}^{\emptyset seat}$	average number of seats in the train [seat.train^{-1}]
$N_{wagon}^{\emptyset\ seat}$	average number of seats in wagon [seat.wagon^{-1}]
$N_{\emptyset\ wagon}^{\emptyset\ train}$	average number of vehicles in train [vehicle.train^{-1}]
N_V	total amount of vehicles [vehicle]
R	reserve [%]
t	operation time [h]
T_h	train hours [train.h]
t_{op}	time of operational preparation of vehicle [h]
t_s	the time of stay in train station [h]
t_t	travel time [h]
V_c	travel speed [km.h^{-1}]
V_o	rate of the turnover vehicles [km.h^{-1}]
W_t	waiting time for the next performance [h]

2. Self-service system

Railway lines and vehicles where is used self-service system are identified by special symbol (Fig. 1). The passengers are obliged to buy transport ticket even before the vehicle onboarding. There are two possibilities how to acquire the ticket by Tsekeris and Souliotou (2014). The passenger can buy common paper ticket or e-ticket. For passenger is usually compulsory to validate transport ticket by marking machine as soon as possible (Konecny and Kostolna, 2015). It could be in railway station, railway stop or in the vehicle.

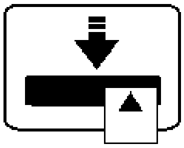

Fig. 1. Pictogram of self-service system. Source: http:tatryportal.sk/doprava.

Flow diagram (Fig. 2) describes the self-service system functionality.

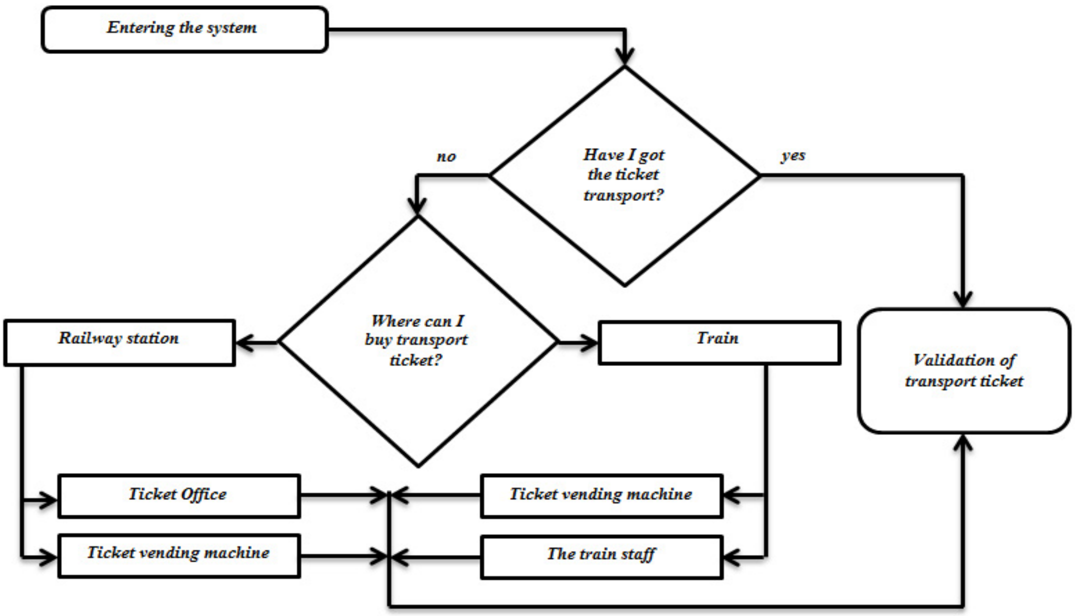

Fig. 2. The self-service system functionality.

2.1. Validation machines placed in railway stations (stops)

Railway stations and stops are places where the passengers can safety onboard and get of the vehicle (train) (Givoni and Rietveld, 2014). One of the possibilities how transport tickets could be validated is locating of validation machines in these places. These locations are affected by various factors:

- location of station building,
- commercial distribution within the railway station (office),

- passengers flow distribution (entrances, exits, underpasses etc.),
- station tracks layout,
- platforms structural design,
- interconnection with the other urban infrastructures.

2.2. Validation machines placed in vehicle

The most common way of markers locating is to place them into the train (vehicle). The passengers usually know this system from the urban public transport. The sum of marking machines is affected by these factors:

- type of the vehicle doors,
- train consist structure,
- number of train sets.

3. The number calculation of the validation machines used in railway stations and stops

The calculation of validation machines number is quite simple for railway stops and railway stations. They could be placed (Wang and Chen, 2014):

- at the beginning of the underpass; it is recommended to place them only to one half of the corridor because they do not collide the passenger streams; the number of the validation machines depends of the passenger streams peak,
- in the underpass at every exit to platforms; minimal one validation machine at every exit,
- at the platforms; minimal one validation machine at every platform.

The calculation of needed number of validation machines in railway stops and stations for railway net in some region is by the formula (1).

$$N_m^{min} = \sum_{i=1}^{n} N_i^p \times n_i^{\emptyset vm} + \sum_{j=1}^{m} N_j^s \times j \times n_i^{\emptyset vm} \quad [number\ of\ validation\ machine] \tag{1}$$

4. The number calculation of the validation machines used in vehicles

The number of validation machines needed in vehicles depends upon (Ponicky et al., 2015):

- types of vehicles doors,
- vehicle consist of train set,
- number of used trainsets.

4.1. Types of vehicle doors

Type of vehicle doors affect the number of used validation machines because the structure can be different depending on the transport purpose, on that the vehicle is supposed to be used for (Cappelli et al., 2014).

Technical solution of used doors can be divided:

- single door – one simple wing with basic (standard) width,
- one and half size – one simple wing (wider single doors),
- double doors – usually two wings with double width.

In case of single wing door there is usually placed one of the markers where passengers can validate their transport tickets. Design of the door physically does not allow more passengers to board on at the same time, so they are in a row one by one. Technical solution of one and half size doors brings faster boarding for passengers but they still can board on only one by one, so the use (number) of markers does not change. Double wings door allow boarding of more passengers at the same time, so that it is necessary to place two markers into these doors.

4.2. The vehicle consist of train set

On the given railway line section the carrier is obligated to ensure traffic and transport performance with its vehicle under the transport service orders.

Traffic performance is determined on the basis of train-kilometers (ordering unit) (Dolinayova, 2013 and Lehutova et al., 2013). The formula for its calculation is following:

$$N_{train.km} = \sum_{i=1}^{n} N_{tr_i} \times L_i \quad [train.km] \tag{2}$$

The transport performance is determined on the basis of seat-kilometers (Dolinayova, 2013). The formula for its calculation is following:

$$N_{seat.km} = \sum_{i=1}^{n} N_{seat_i} \times L_i \quad [seat.km] \tag{3}$$

The proportion of these indicators determines an amount of seats in the train (train set consist). This indicator is important for resulting amount of validation machines. The formula for seats quantity calculation is following:

$$N_{train}^{\emptyset\, seat} = \frac{N_{seat.km}}{N_{train.km}} \quad [seat.train^{-1}] \tag{4}$$

4.3. Number of train sets

Another factor that affect number of validation machines in a vehicle is the number of train consists (train sets), that carrier has available to ensure traffic operation on given railway line section.

At first, it is necessary to determine the train hours that specify how is the time period of serviced activity in conditions of selected line section performance. Calculation formula is:

$$T_h = \frac{N_{train.km}}{V_o} \quad [train.hours] \tag{5}$$

Turnover rate of railway vehicles depends on the length of line section, travel time and well time in the station. In terminal station (terminus) it is needed to calculate with an additional time of operational preparation of vehicle (cleaning, refilling of water, etc.) and the waiting time for the next performance (Fig. 3).

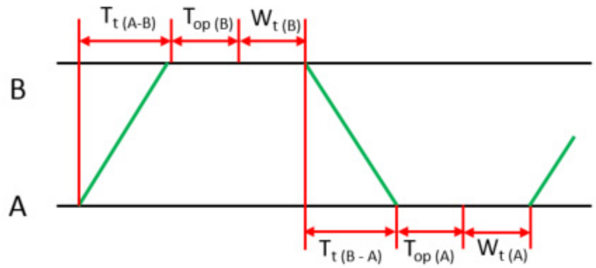

Fig. 3. The train set turnover period.

Formula for calculating the rate of turnover follows:

$$V_0 = \frac{2 \times L}{\left(t_{t(A-B)} + \left(\alpha_{r(A)} + \alpha_{z(B)}\right) + t_s + t_{op(B)} + W_{t(B)}\right) + \left(t_{t(B-A)} + \left(\alpha_{r(B)} + \alpha_{z(A)}\right) + t_s + t_{op(A)} + W_{t(A)}\right)} \quad [km.h^{-1}] \tag{6}$$

Turnover rate of railway vehicles can also be calculated using a traveling speed. However, in this case, the time of operational preparation of vehicle and waiting times is not considered. At the beginning of calculation it is necessary to pre-calculate proportion of travel time, cleaning time and the waiting time for the next performance (Sekulová et al., 2014). Consequently, the cruising (traveling) speed is multiplied with this factor that results in a turnover rate of train sets. The following formulas are:

$$V_c = \frac{L}{t_t + (\alpha_r + \alpha_z) + t_s} \quad [km.h^{-1}] \tag{7}$$

$$k_{TT} = \frac{t_t + t_{op} + W_t}{t_t} \quad [-] \tag{8}$$

$$V_o = V_c \times \frac{1}{k_{TT}} \quad [km.h^{-1}] \tag{9}$$

The total amount of vehicles is set as the ratio of the train hours and operating time on the line section. It is very important to take in consider the reserve of value 15% in case of disturbances (disorders, small repairs etc.) The formula is:

$$N_v = \frac{T_h}{t} \times \left(1 + \frac{R}{100}\right) \quad [total\ amount\ of\ vehicle] \tag{10}$$

Total number of validation machines in vehicle is provided on the base number of vehicle (train consist structure), number of doors, coefficient of doors and total amount of vehicles. The formula is:

$$N_{\emptyset\,wagon}^{\emptyset\,train} = \frac{N_{train}^{\emptyset\,seat}}{N_{wagon}^{\emptyset\,seat}} \quad [number\ of\ vehicle] \tag{11}$$

$$N_m = \left(\frac{\frac{N_{seat.km}}{N_{train.km}}}{N_{wagon}^{\emptyset\, seat}} \times N_d \times K_D\right) \times \left(\frac{\frac{N_{train.km}}{V_c * \frac{1}{k_{TT}}}}{t} \times \left(1 + \frac{R}{100}\right)\right) [number\ of\ valid.machine] \quad (12)$$

$$N_m = \frac{N_{seat.km} \times N_d \times K_D \times k_{TT} \times \left(1 + \frac{R}{100}\right)}{N_{wagon}^{\emptyset seat} \times V_c \times t} [number\ of\ validation\ machine] \quad (13)$$

where: $K_D = 1$ for single doors,
$K_D = 1$ for one and half size doors,
$K_D = 2$ for double doors.

5. Application of the methodology in praxis

Methodology of validation machines calculation is applied for the High Tatras region in Slovakia. This region is situated in the north part of Slovakia near border with Poland. It is the very famous region of national natural park with high density of tourists. Railway transport is a main public transport mode there. Railway infrastructure connects main towns and villages in this region. It is an independent railway system and its name is Tatra´s electric railways (TER). Scheme of TER is at a Fig. 4.

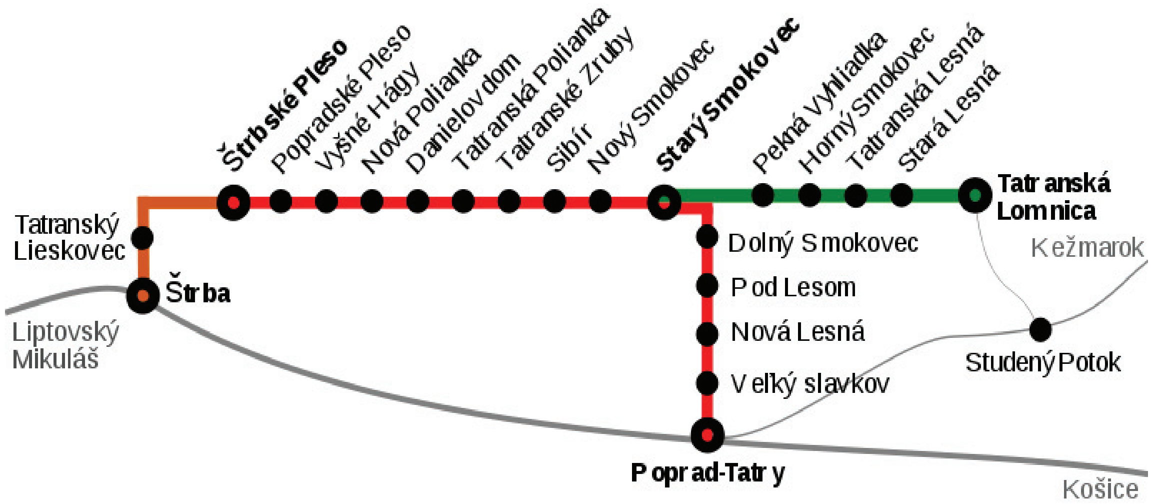

Fig. 4. Scheme of Tatras electric railways. Source: https://commons.wikimedia.org.

TER consists of:

- conventional adhesion narrow gauge railway lines Poprad-Tatry – Strbske Pleso (red line at Fig. 4) and Tatranska Lomnica – Stary Smokovec (green line at Fig. 4),
- cog-railway line Strba – Strbska Pleso (brown line at the left side of the Fig. 4).

Calculation is done for the conventional adhesion railway lines. Basic characteristics of these lines are in Table 1.

Table 1. Basic characteristics of Tatras electric railways.

Characteristic	Railway line Poprad-Tatry – Strbske Pleso	Railway line Tatranska Lomnica – Stary Smokovec	Both lines together
Length [km]	29	6	35
Number of railway stations	7	2	9
Number of stops	8	4	12
Maximum track speed [km.h^{-1}]	60	60	-
Travel time [min]	73	14	-
Number of line tracks	1	1	-

Source: Zeleznice Slovenskej republiky.

Railway passenger operator Zeleznicna spolocnost Slovensko, a.s. uses electric railway triple unit trains with the series number 425 at TER (Fig. 5). More characteristics about railway unit is in the Table 2.

Fig. 5. Electric railway triple unit train with series number 425 in High Tatras region. Source: http://www.zelpage.cz.

Table 2. Characteristics of electric railway triple unit train with series number 425.

Characteristic	Value
Maximum speed [km.h^{-1}]	80
Number of doors	4
Type of the doors	double
Number of seats	108

Source: https://sk.wikipedia.org.

If validation machines are placed in railway stations and stops it is necessary to use 35 of them calculated by formula (1). Calculation is in Table 3.

Table 3. Calculation of needed validation machines for the railway stations and stops.

Railway station/stop	PP-Tatry	V. Slavkov	N. Lesna	Pod Lesom	D. Smokovec	S. Smokovec	N. Smokovec	Sibir	T. Zruby	T. Polianka	Danielov dom	N. Polianka	V. Hagy	P. Pleso	S. Pleso	T. Lomnica	S. Lesna	T. Lesna	H. Smokovec	P. Vyhliadka
N_i^p	2	1	-	1	-	1	-	-	-	1	-	-	1	-	2	1	-	-	-	-
j	-	-	1	-	1	-	1	1	1	-	1	1	-	1	-	-	1	1	1	1
$n_i^{\emptyset vm}$	2	2	1	2	1	4	1	1	2	2	1	1	2	1	2	2	1	1	1	1
$N_i^p \times n_i^{\emptyset vm}$	4	2	-	2	-	4	-	-	-	2	-	-	2	-	4	2	-	-	-	-
$j \times n_i^{\emptyset vm}$	-	-	1	-	1	-	1	1	2	-	1	1	-	1	-	-	1	1	1	1
N_m^{min}	35																			

If validation machines are placed in railway vehicles it is necessary to use 66 of them calculated by formula (13).

$$N_{m1} = \frac{200\,000 \times 4 \times 2 \times 1{,}42 \times \left(1 + \frac{15}{100}\right)}{108 \times 23{,}84 \times 19} = 53\ validation\ machines\ (PP - Tatry - S.Pleso) \tag{14}$$

$$N_{m2} = \frac{35\,000 \times 4 \times 2 \times 2{,}14 \times \left(1 + \frac{15}{100}\right)}{108 \times 25{,}71 \times 19} = 13\ validation\ machines\ (T.Lomnica - S.Smokovec) \tag{15}$$

Conclusions

The railway transport is an environmental friendly mode of transport which is very important for mobility of inhabitants in regional transport as well. Transportation is a charge service and it is usually necessary to check validity of the transport tickets.

The passengers can buy their common paper tickets or e-tickets at railway stations (stops), customer centers or by internet and mobile applications nowadays. If the validation of the tickets is necessary, it could be done by employees of the carriers or it is possible to create self-service system for validation of the tickets. The advantage of self-service system creation in regional public passenger transport is to reduce personal costs for carriers.

Validation machines could be placed to railway stations and stops or to the railway vehicles to create effective self-service system.

The needed number of validation machines placed in railway stations and stops depends upon place where they are placed, number of stations and stops, number of railway tracks and platforms in stations and stops, average number of validation machines at one platform.

The needed number of validation machines placed in railway vehicles increases with transport performance, number of doors in wagons and depends upon used doors type, travel time utilization index and reserve of vehicles.

The needed number of validation machines placed in railway vehicles decreases with growing capacity of wagons, travel velocity and operation time and does not depend upon conveying performance.

The methodology for calculating the quantity of validation machines in railway transport can help to make relevant decision for carriers if it is more effective to install the validation machines to railway stations (stops) or to the railway vehicles.

Acknowledgements

This paper is prepared with the support of the projects:

- KEGA 026ŽU-4/2015 Innovative approaches in system of teaching management in the study program Railway transport with a focus on application the dynamic quality models in the railway transport,
- KEGA 010ŽU-4/2016 Innovation of training of railway engineers with support of terminological dictionary in scope of railway operations,
- VEGA 1/0095/16 Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system.

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