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Railway Traffic Organization Model Considering Allocation of Platform Edges for Passenger Trains

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ABSTRACT

Movement of trains on the railway network, due to the need to conduct them in a smooth, safe and stable manner, must be properly structured. This arrangement is defined as the organization of railway traffic. One of the significant problems associated with the organization of traffic is the construction of the timetable. Timetable should be constructed in such a way as to avoid blockages mainly before operating control points. It can not be allowed to occur that the train will wait for the preceding train to release the platform edge. During building the mathematical models supporting the construction of the timetable should therefore take into account this problem. The article presents selected elements of the mathematical model of timetable construction of the passenger trains, taking into account the problem of the perimeter edges allocation. The formal record of the model, the input data necessary for its operation and the sought values were presented. Boundary conditions and indicators for the quality of the solution have been discussed. An example of model works on real data.

KEYWORDS: railway traffic, organization, train timetable, platform edges

1. Introduction

The movement of trains on the railway network, due to the specificity of this mode of transport, must be properly organized. With the movement of trains involves a number of organizational issues and in particular: determining the order of trains on open lines, determining travel times, determining open line time spacing and station time spacing, determining overtaking and crossing places, determining the types of train sets necessary to perform tasks and their parameters, determining the division of tasks and other.

The above allows to conclude that the problem of railway traffic is a complex decision problem. This is determined not only by the participation of a wide spectrum of participants but also by the technical and operational conditions. In order to meet all these requirements, proper organization of railway traffic is necessary [24, 29, 33, 35]. The proper organization of railway traffic requires a number of activities resulting from legal conditions [10]. Among the elements of the railway traffic organization can be distinguished (Fig. 1):

- determining the amount of transport demand - how many passengers and / or what amount of cargo (traffic flow) is to be transported in specific relations and at what time (this activity is carried out by the railway undertaking based on the market analysis),
- determining the routes of communication lines (routes of transport) - determination of routes which will be used to move traffic flow and allocation of train composition to service, frequency of running and leading hours,
- construction of the graphic train timetable - scheduling of the movement of individual trains in time and in space,
- train traffic plan on the railway network - designation of tracks on open lines and operating control posts, on which trains will move and places where stops will be carried out,

- rolling stock movement plan on the railway network - allocation of traction vehicles and train sets to train (circulation of locomotives and train sets),
- work plan for train and traction crew - allocation of trains to the traction crew, as well as the train crew,
- shunting work plan and operating support facilities - assigning shunting crews to each station together with shunting locomotives, as well as preparing a plan for servicing traction vehicles and wagons by maintenance facilities.

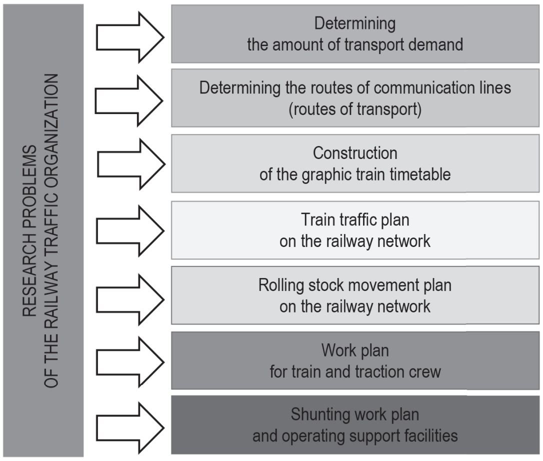

Fig. 1. Research problems of the railway traffic organization [own study based on [10]]

As it results from the above, the organization of railway traffic is conditioned by many technical, organizational and legal factors. A railway work plan, which is a train timetable, is a very important element of the railway transport organization [4, 35]. It is created based on the graphic train timetable. It is the basis for the development of: train traffic and rolling stock plan on the railway network, a plan for the work of train and traction crews, as well as a shunting work plan and a maintenance base.

Timetables should be constructed in such a way as to avoid traffic congestion mainly in front of traffic stations. It cannot be allowed to occur that the train will wait for the preceding train to release the platform edge. Building the mathematical models supporting the construction of the timetable should therefore take into account this problem. The article presents selected elements of the mathematical model of constructing the timetable of passenger trains, taking into account the problem of the platform edges allocation. The formal record of the model, the input data necessary for its operation and the decision variables were presented. Boundary conditions and indicators for the quality of the solution assessment have been discussed. In addition, an example of using the model to develop a timetable for a selected railway line in Poland was presented.

2. Decision problems of the train timetable construction

The construction of a train timetable is one of the important areas of railway traffic organization. A number of decision problems are related to the construction. The first of these is the choice of the type of timetable that will be best suited to the needs of passengers and customers sending / receiving loads. There are many divisions of train timetables in the literature. Among the basic types can be distinguished:

- periodic timetables [35] – in which trains in certain directions began with a fixed end of minutes, unchanged throughout the day,
- symmetric timetables [22] – in which trains arrive at a specified end of minutes to the given station, whereas they are began in the same direction at a specified end of minutes located in relation to a fixed axis of symmetry,
- cyclic timetables [6, 21, 23] – in which trains in a given direction are began in a fixed cycle, e.g. every 30 minutes,
- integrated cyclic timetables [9] – in which trains of different categories in a given direction are began in a fixed cycle, e.g. every 30 minutes.

During constructing the timetable it should be noted that various types of conditions resulting from the specificity of traffic, e.g. in the case of High Speed Railway, should be adapted to the demand and the extended braking distances should be taken into account [35]. This forces the need for larger security buffers.

It should be noted that a well-designed train timetable must enable the provision of services at an appropriate level [28]. In the literature, the most important features of the timetable are indicated:

- stability at the level of the open line [36] – timetable should have guaranteed to be easy to return to the equilibrium (basic timetable) after the disturbance on the open line,
- stability at the level of the station [37] – timetable should have guaranteed to be easy to return to the equilibrium (basic timetable) after the disturbance on the station,
- synchronization [38] – timetable should take into account the relevant connection between trains of different railway undertakings and different categories,
- taking restrictions into account [39] – timetable should take into account all restrictions from both infrastructure and superstructure elements as well as from the demand of service buyers and service providers,
- punctuality [36] – timetable should enable traffic to be carried out in a punctual manner,
- resistance [40] – timetable should be constructed in such a way as to be immune to disturbances at both the station and the open line,
- nominal [40] – timetable must contain mechanisms that would make it immune to interference.

Organization of rail traffic is primarily a proper management of railway traffic. The train timetable is a tool dedicated to railway traffic management. The timetable determines the organization of transport services in a planned, timely and economical manner, ensuring convenient connections, traffic safety and regular communication service. In the literature on the subject, the basic functions of timetables are [13, 14]:

- planning function - timetable allows for adjust the intensity of the transport service to the flow of passengers and cargo, that is, variable transport tasks and permanent and temporary needs in the horizon of usually one year,

- schedule function - timetable allows for adjust the dates of running trains and the number of stops to the volume of transport needs,
- concretizing function - timetable allows for concretization of conditions and transport possibilities, such as train set circulation, determination of transport routes etc.,
- coordinating function - establishing communications between individual trains and other means of transport at stations and between individual trains on a given railway line,
- organizational function - organizing the work of railways and employee teams that support the movement process and the impact on the external surroundings of rail transport - regular communication favours the urbanization process,
- railway traffic management function [8, 9, 20, 26, 27] – enabling traffic control.

Train timetable is the basis for the development of many documents necessary for the proper functioning of the railway, including [11]:

- work schedules for both traction and train crews [1], [30],
- locomotive circulation [12],
- other traction and non-traction vehicles circulation [32],
- transport of loaded and empty cars [15],
- allocation of platform edges at stations [5, 7].

As mentioned above, the subject of the article is the construction of the timetable, taking into account the problem of the allocation of platform edges at individual stations, and especially at the beginning and final stations. This problem can be defined as assigning stop of specific train to a particular platform edge in a particular operating control point. When solving this problem, it should be ensured that trains run as far as possible at maximum speeds and that there is no situation that reduces the flow of traffic.

There are a limited number of platform edges at the stations which may cause the next train to be forced to stop for the previous one to release its edge. This situation is shown in Fig. 2.

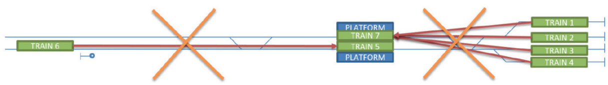

Fig. 2. The problem of the lack of free platform edge [own study]

There are a limited number of holding tracks at the final stations, which may cause the next train to be forced to occupy for a long time platform edge while waiting for the hold track to be released. This situation is shown in Fig. 3.

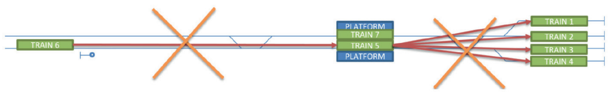

Fig. 3. The problem of the lack of free hold tracks [own study]

3. Elements of the mathematical model of the train timetable construction

3.1. Parts of the mathematical model of the train timetable construction

The model of the train timetable construction (MKRJ) was prepared in accordance with the approach used for modelling transport systems described inter alia in the works [1, 2, 16, 17, 18, 19, 25, 31, 34]. It contains the following elements:

- structure of the railway network located in the selected area (***GK***) i.e. point elements of the railway transport infrastructure ***WK*** – operating control posts and expeditionary points and linear elements ***NOLK*** – connection between operating control posts and expeditionary points:

$$\boldsymbol{GK = \langle WK, NOLK\rangle} \quad (1)$$

- characteristics of elements of the railway network structure located in a selected area (***FK***) – characteristics of expeditionary points **FWK** among others average stop time in the point, the ability to finish and begin the run, the number of tracks at the operating control point, the number of holding tracks at the begin / final station and the characteristics of section of railway lines **FNOLK** (and open lines **FSZL**) – including travel time, length of the section:

$$\boldsymbol{FK = \langle FWK, FNOLK, FSZL\rangle} \quad (2)$$

- demand for transport matrix - volume of transport tasks (**ZP**):

$$\mathbf{ZP}(t,kpc) = [zp\,(t, kpc, wk, wk')]_{WKXWK}$$
$$\text{where } zp(t, kpc, wk, wk') \in \mathrm{N},\ t \in \mathbf{T},\ kpc \in \boldsymbol{KPC},\ wk, wk' \in \mathbf{WK} \quad (3)$$

- train categories (KPC) /kpc, kpc' – category number, KPC – number of categories /:

$$\boldsymbol{KPC} = \{kpc : kpc = 1, ..., kpc', ..., \boldsymbol{KPC}\} \quad (4)$$

- periods for which the day has been divided (***T***) /*t*, *t'* – period number, *T* – number of periods/:

$$\mathbf{T} = \{t : t = 1, ..., t', ..., T\} \quad (5)$$

- types of train sets that can run on the analysed area of the railway network - cars and traction vehicles (***TP***) /*tp*, *tp'* – train set number, *TP* – number of train sets/:

$$\mathbf{TP} = \{t : t = 1, ..., t', ..., TP\} \quad (6)$$

- transport offer (**OP**),
- graphic train timetable (**WR**).

Bearing in mind the above model **MKRJ** can be represented as ordered eight:

$$\boldsymbol{MKRJ = \langle GK, FK, ZP, KPC, T, TP, OP, WR\rangle} \quad (7)$$

where:

GK – structure of the railway network,
FK – characteristics of elements of the railway network,
ZP – demand for transport volume,
KPC – train categories,
T – periods for which the day has been divided,

TP – types of train sets,
OP – transport offer,
WR – graphic train timetable.

Therefore, in order to construct a train timetable it is necessary to know the structure of the railway network ***GK*** located in the analysed area and its characteristics ***FK***, data on the transport needs ***ZP***, division into categories of trains ***KPC*** and periods of day ***T***, types of trainsets ***TP*** possible to use and transport offer ***OP*** and graphic train timetable ***WR***.

3.2. Optimization task of timetable construction

Formulation of the optimization task of the train timetable construction can be presented as follows:

For the data specified in point 3.1

determine the values of decision variables:

- *z(lk)* on the interpretation of the use of the communication line number *lk* (*lk* ∈ ***LK***) for passenger transport /**LK** – set of communication lines/:

$$\mathbf{Z} = [z(lk): z(lk) \in \{0,1\},\ lk \in \mathbf{LK}] \quad \mathbf{(8)}$$

- *znp(a)* on the interpretation of the amount of transport demand for a given communication line with the number *a* (*a* ∈ **A**) /**A** – set of communication lines whose beginning and end is at the point where trains can finish and begin running/:

$$\mathbf{ZNP} = [znp(a):\ znp(a) \in N,\ \ where\ a \in \mathbf{A}] \quad \mathbf{(9)}$$

- x(a,tp,flkom(a),poc(a),gw(poc(a),wk),t,kpc) on the interpretation of the assignment for communication lines with numbers lk (lk∈LK): vehicle type with number tp (tp ∈TP) to service and frequency of running flkom(a) for a specific category of trains kpc (kpc∈KPC) in a given period t (t∈T):

$$X = \begin{bmatrix} x(a,tp,flkom(a),poc(a),gw(poc(a),wk),kpc,t): \\ x(a,tp,flkom(a),poc(a),gw(poc(a),wk)kpc,t) \in \{0,1\} \end{bmatrix} \quad \mathbf{(10)}$$

$$where: a \in A, tp \in TP, wk \in WK, kpc \in KPC, t \in T$$

additionally:

- set of train numbers ***POC(a)*** to be run on a specific communication line a *(a ∈ A)*,
- for each train *poc(a)* suggested time - *gw(poc(a),wk)* of its start from the beginning point is indicated,
- *y*(*lr*(*poc*(*a*))) on the interpretation of compliance with the principles of safe and smooth running of railway traffic and the maximum fulfilment of the needs of participants of the transport process placing on the graphic train timetable *lr*(*poc*(*a*)) related to train *poc*(*a*):

$$Y(a) = \left[y(lr(poc(a))) : y(lr(poc(a))) \in \{0,1\} \right] \quad \mathbf{(11)}$$

additionally:

- timetable for the train marked with the number *rj(poc(a))* developed for the communication line a *(a ∈ A)*,

under constraints:

- each communication line for each category of trains and all periods of the day should be served by the specified train set with a specific frequency,
- the number of trains of a given type allocated for servicing all communication lines of all categories during all periods of the day must be lower than or equal to the number of trains of a given type owned by the railway undertaking,
- the volume of the passenger flow to be transported in direct relations over a given communication line must be less than or equal to the supply of seats on this line,
- the volume of the passenger flow to be transported in direct relations over a given communication line of a particular category of trains must be smaller than or equal to the flow to be transported from the starting point to the final point,
- the volume of the passenger flow to be transported in direct relations over a given communication line must be non-negative,
- the scheduled speed on a given section should be the minimum of: the maximum speed for the section and the speed allowed for the train set,
- the length of the train set should not be longer than the maximum length of the train set of each category allowed for a given section of the railway line,
- the train set length should not be longer than the maximum length of the train set of individual categories allowed for a given expeditionary points,
- running frequency on the communication line must be between the minimum and maximum frequency values for the communication line,
- proposed start time for trains of different categories should be different,
- number of trains at a given node at a given moment can not exceed the number of available platform edges,
- number of trains terminating at a particular node at a given moment can not exceed the number of holding tracks at the disposal,
- initial node on the graphic timetable (symbolizing the moment the train appears on the graphic timetable) for a given train *poc*(*a*) can have only one outgoing state,
- for the intermediate node on the graphic timetable (symbolizing the moment of the train state change on the graphic timetable) for a given train the number of incoming states must be equal to the number of outgoing states,
- end node on the graphic timetable (symbolizing the moment the train disappears on the graphic timetable) for a given train can have only one incoming state,
- for each vertex the difference between the arrival of the next train and the departure time of the train must be greater than or equal to the length of the station time spacing,
- for each vertex, the moment of departure of the next train must be greater than or equal to the departure time of the train increased by the length of the open line time spacing,
- for each vertex being a place where trains can end and start running, the difference between the departure of the next train and the arrival time of the train should be greater than or equal to the time of communication for the node,
- the number of trains on the route should not exceed the sum of the number of intervals to which the sections constituting this open line are divided,

in order to criteria functions in form:

- $F_1(\mathbf{Z})$ – quality assessment index of the solution describing the minimization of the length of communication lines *lk* / *dlk*(*lk*) – length of communication lines/:

$$F_1(Z) = \sum_{tk=LK} z(lk)dlk(lk) \longrightarrow \min \tag{12}$$

- $F_2(\mathbf{ZNP})$ – quality assessment index of the solution describing the volume of transported demand on all communication lines and all categories of the trains *kpc* and in all periods of the day *t* without the need to change:

$$F_2(ZNP) = \sum_{a \in A} znp(a) \longrightarrow \max \tag{13}$$

- $F_3(\mathbf{X})$ – the quality assessment index of the solution describing the amount of operating costs *ko*(*tp*) related to the running of trains *poc*(*a*) supported by train sets *tp* along communication lines *a* with length $\sum_{lk \in LK} dlk(lk)$:

$$F_3(X) = \sum_{tp \in TP} \sum_{a \in A} \sum_{wk \in WK} \sum_{kpc \in KPC} \sum_{t \in T} \sum_{lk \in LK} x1ko(tp)dlk(lk)POC(a) \longrightarrow \min \tag{14}$$

- $F_4(\mathbf{X})$ – the quality assessment index of the solution describing the number of trains of different types *tp* needed to service trains of different categories *kpc* in all periods of the day *t* / *nolk* – number of the railway line section, ***NOLK*** – set of sections of the railway line, *lhlkom*(*a*) – number of running hours on the communication line, *tj*(*nolk*,*tp*) – travel time of the section *nolk* by train set type *tp*, *tpost*(*wk*,*kpc*) – average stopping time in point *wk* of train with category *kpc*/:

$$F_4(X) = \sum_{tp \in TP} \sum_{kpc \in KPC} \sum_{t \in T} \sum_{a \in A} \sum_{wk \in WK} \sum_{nolk \in NOLK} x1 \frac{2(lhlkom(a)\left|\frac{60}{flkom(a)}\right|)(tj(nolk,tp) + tpost(wk,kpc))}{60lhlkom(a)} \longrightarrow \min \tag{15}$$

- $F_5(\mathbf{Y})$ – the quality assessment index of the solution describing total duration *tj*(*lr*(*poc*(*a*))) of states *lr*(*poc*(*a*)) of trains *poc*(*a*) for a given communication line *a*:
-

$$F_5(Y) = \sum_{lr(poc(a)) \in LR(a)} \sum_{poc(a) \in POC(a)} y(lr(poc(a)))tj(lr(poc(a))) \longrightarrow \min \tag{16}$$

achieve extreme values.

4. Algorithm of solution and case study

4.1. The algorithm for solving the problem of train timetable construction

To develop a model of the timetable construction should be:

- define and parameterize the area for which the train timetable will be prepared,
- develop a transport offer:
  - determine the amount of transport demand,
  - determine the routes of communication lines, which will be considered within the area and should be parameterized accordingly,
  - determine the number of passengers on individual communication lines,
  - define and parameterize train sets that can be used in a specific area,
  - determine the characteristics for communication lines in terms of the needs and possibilities of their operation by individual train sets,
  - determine the parameters of the train sets directed to service a specific communication line,
  - assign the frequency of running set in the previous step train composition over the communication line,
  - develop proposals for train numbers to be run and preferred hours of their start from the first expeditionary point,
- develop a graphic train timetable (apply the developed transport offer to train timetable):
  - set out exploitation points where trains can end and start running and where stops will take place,
  - determine the stop times of trains at individual exploitation points and the travel time between individual exploitation points,
  - specify the values of the times that are necessary for the proper construction of the graphic timetable (including crossing time, time spacing etc.),
  - determine the train numbers that will run over the area covered by the construction of graphic timetable,
  - define priorities for running trains on the railway network,
  - put on the canvas of graphic train timetable,
  - eliminate collisions of train paths on graphic timetable (if there are),
  - determine for each exploitation points the arrival and departure times of individual trains.

4.2. Case study of train timetable construction

For the purpose of this article, the train timetable for the railway line 326: Wrocław Psie Pole - Trzebnica was developed. The research was carried out using the proprietary BEERJ application. For the needs of the research, it was assumed that:

- the line is not electrified,

- passenger traffic will be carried out on the section Wrocław Psie Pole - Trzebnica,
- execution of passenger transport: Koleje Dolnośląskie company using railway buses,
- it was assumed that trains may end and start running at exploitation points: Wrocław Psie Pole and Trzebnica,
- it was assumed that a small number of passengers will choose railway transport for daily travel,
- during manually adjusting of train paths in the graphic timetable to the needs of passengers, the goal was maximization of time buffers allowing the elimination of delays,
- size of transport needs was obtained from traffic surveys conducted for the Wrocław agglomeration.

For the needs of the research, all necessary data regarding: exploitation points and their characteristics, sections of railway lines and their characteristics, open lines and their characteristics, transport needs, communication lines and their characteristics, vehicle types and their characteristics were defined.

As a result of the work, it was established that there are two communication lines that have a beginning and end in places where trains can end and start running

- z(1) = 1 – Wrocław Psie Pole – Trzebnica à lkomss(1,1,1) = 1,
- z(2) = 1 – Trzebnica – Wrocław Psie Pole à lkomss(2,1,1) = 1.

Then, on the basis of calculations, the following volume of the traffic flow was allocated: *znp*(1,1,1) = 4683 pass., *znp*(2,1,1) = 4683 pass. For the appropriately parameterized vehicles, the following train sets and frequency type assignment was assigned to communication lines:

- x(1,5,66,{101,103,…,143},({00:00,01:06,…,23:06},1),1,1)- to communication line 1 has been assigned train set SA134 runs at a frequency of 66 minutes; trains numbers 101, 103, …, 143 should be started from operating point number 1 at 00:00, 01:06, …, 23:06; day period 1 and category 1,
- x(2,5,66,{102,104,…,144},({00:00,01:06,…,23:06},7),1,1)- to communication line 2 has been assigned train set SA134 runs at a frequency of 66 minutes; trains numbers 102, 104, …, 144 should be started from operating point number 7 at 00:00, 01:06, …, 23:06; day period 1 and category 1.

After calculations, liquidation of collisions between reference routes and manual correction of the graph, the following graphic timetable was obtained, which took into account the problem of the platform edge allocation - see Fig. 4.

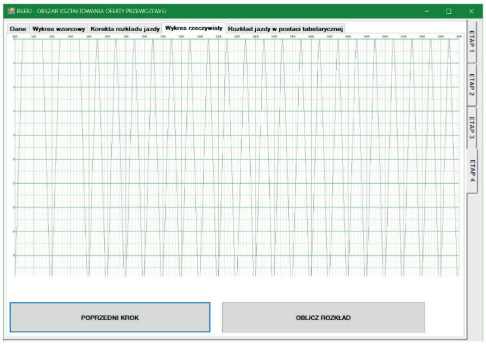

Fig. 4. Graphic timetable for line 326 [own study using the BEERJ application]

5. Conclusion

Movement of trains on the railway network, due to the need to preserve the highest degree of safety, must be appropriately ordered. The connection of all problems on the railway network to each other should be implemented in such a way that they bring the best results with the proper use of technical means and with the least number of people needed to operate them. Among research areas related to the problem of organization of railway traffic, the construction of the train timetable has an important place.

A well-constructed timetable allows for conducting of movement smoothly and safely. In prepared timetable should be taken into account the time associated with any determinants - e.g. adequate time to change of the passengers, the time required to realize train announcing by train dispatchers, time of non-simultaneous arrival etc.

Taking into account in the problem of the construction the platform edges allocation will avoid the situation that the train will wait before the entry semaphore to the station until the platform edge for its will released or the edge is blocked because there is no access for stabling track for its.

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