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MODEL OF SHUNTING TECHNOLOGY BASED ON SYSTEM STRUCTURE

ABSTRACT

Railway transport is facing a growing liquidity problem. The major problem in small systems is the detention of wagons at marshalling yards, which prolongs the time of freight travel. To avoid this problem it is of great importance to search for parameters that would enable creation of a model of technology that would provide shorter wagon detention time at stations as well as optimising the number of marshalling yards for small systems. It is at the same time a great opportunity to search for a link between the shunting work in the railway transport and the theoretical system approach which presents it as a current scientific problem. In classical technology the shunting work is carried out with no application of and no regard for the system approach. With new shunting systems in the railway transport the regard for theory of transport systems is crucial as the secondary level of classical methods.

As already pointed out, from the theoretical point of view an important contribution will be made to the use of system theory for shunting purposes, since the suggested model effectively provides the approach of analysing separate elements in the railway transport structure into integral shunting operations at the railway stations.

KEY WORDS

technology, shunting, railway, system, structure, optimisation

1. INTRODUCTION

International trade as well as the integration of Slovenia into the European Union requires fast development and adjustment of the railways according to the offer of transport services. Rationalisation of transport services is necessary, which leads to great changes in organisation of transport and transport capacities, particularly the infrastructure.

The basic characteristics of organising the flow of wagons and, accordingly, placing and dimensioning of shunting capacities are defined according to the following factors:

- number of destinations,
- factor of wagons alignment,
- average number of wagons in the train formation at forwarding,
- cost of wagon hours of aligning the wagons,
- number of transit wagons that are being re-marshalled,
- number of wagons that transit without re-marshalling,
- saving of time with transit wagons without re-marshalling,
- cost of wagon hours at additional re-marshalling, and
- collective cost of wagon hours of alignment and re-marshalling.

The progress of shunting capacities depends on the perspective rational plan of shunting tasks of separate railway stations that are selected by means of complex and joint analyses of the whole shunting system. While defining the capacities the whole shunting system of the railway network has to be considered and not only the station that is carrying out the task.

The analysis has to deal with concentration of basic work at introducing direct trains to a smaller number of marshalling yards with larger capacities. The stations have to be equipped with modern shunting facilities in order to achieve optimal effect of the shunting procedure and thus the optimal organisation of the flow of wagons and reduction of exploitation costs are assured.

To enable rational defining of shunting capacities at the Slovenian Railways it is important to find out the perspective flows of wagons and other factors that influence dimensioning of the shunting capacities. By means of the analysis of the wagons flow on relation Maribor-Tezno – Pragersko – Celje-Čret – Zalog, a shunting model for small systems was created, using the mathematical model for analysis of the flow of wagons. Using the example of four successive stations it was established that in case of the Slovenian Railways and other smaller railway directions the above mentioned model is adequate in order to determine the flow of wagons, which is fundamental for dimensioning of the marshalling yards.

2. ORGANISATION OF FLOW OF WAGONS

Analysis of the organisation of the flow of wagons shows that all the authors dealing with the shunting problem estimate all the ways of organising the flows according to the costs that appear as consequence of the time needed for alignment of wagons, and according to the costs that appear due to the re-marshalling of train formations at technical railway stations. The change of organisation of flow of wagons directly affects the time of alignment of wagons. However, the time of alignment cannot be used as the saving time index of detention. The saving time of detention at technical stations in regard to transit wagons without re-marshalling is defined as follows:

$$t_p = t_{pd} - t_{tr} - t_n$$

The re-marshalling time is defined by the following formula:

$$t_{pd} = t_{tk} + t_{rs} + t_n + t_f + t_{od} + t_{č}$$

The saving time can be defined in the following way:

$$t_p = t_{tk} + t_{rs} + t_n + t_f + t_{od} + t_{č} - t_{tr} - t_n$$

As regards the knowledge of techniques and technology of work at marshalling yards, it has been established that change of organisation of the flow of wagons barely influences: the time of re-marshalling t_{pd}, the time of splitting a train formation t_{rs}, the time of re-alignment of a train t_f and the time needed for dispatch of a train t_{od}. The change in organisation of the flow of wagons directly affects the time of aligment of wagons and, to some extent, the time of detention of wagons. With good organisation of the flow of wagons and adjustment of technological process of work at stations the time of detention or the unproductive time can be reduced to a minimum. The function of the criterion is defined in such a way that the time of alignment and the time of re-marshalling are at their minimum. The problem is presented by means of linear programming. The application of linear programming provides an optimal solution of the problem. It means that in order to solve the problem a theoretical basis of a possible variant is applied, and by means of linear programming the process of attaining the optimal solution of the task is shorter.

Optimal organisation of the flow of wagons is presented for four marshalling yards, i.e. the stations that were included in the research of shunting techniques in the railway transport. The selected stations include: Maribor-Tezno, Pragersko, Celje-Čret and Zalog.

2.1. Optimising the flows of freight

Each train formation can theoretically be dispatched as a direct train or not. Whether the train formation will be dispatched as a direct train depends on numerous parameters:

1. frequency of all trains, not only the handled one;
2. time of alignment of wagons at all technical stations included in the research;
3. average number of wagons in the train;
4. time saving at each technical station due to transit of wagons without re-marshalling.

To simplify work, two conditions are introduced:

$X_{ij} = 0$, i. e. train formations are not dispatched as direct trains;

$X_{ij} = 1$, i. e. train formations are dispatched as direct trains.

Thereby, the area of the definition of the problem is fully defined, i. e:

$$0 \le X_{ij} \le 1$$

X_{ij} must be integer

$$i = 3,4,\ldots,n; \quad j = 1,2,3,\ldots,(i-2).$$

Each train formation can also be re-marshalled at each intermediate technical station or it can be transited without re-marshalling. Therefore, another variable is introduced for each train formation and for each destination – technical station that would assist showing whether the train is being re-marshalled at separate stations. This is the variable X_{ijk}. Index »ij« indicates which train formation it applies to, and index »k« indicates which technical station it applies to.

The train formation that transits more than one technical station can be changed into a direct train, where the variable is X_{ij} = 1; all other variables that indicate re-marshalling of trains at intermediate technical stations, equal nought or the train formation cannot be directly dispatched to its destination. The following scheme shows flows of freight.

The flows of freight 4. 2. are direct trains, here the following conditions are given:

$$X_{4,2,3} = 0 \Rightarrow \begin{array}{l} X_{4,2} = 0, \quad X_{4,2,2} = 0, \\ X_{4,2} + X_{4,2,2} + X_{4,2,3} = 1. \end{array}$$

The second example: not direct trains are dispatched but a train is made up of the flows 4.2 and 3. 1; here the following conditions are given:

$$X_{4,2,3} = 1 \Rightarrow \begin{array}{l} X_{4,2} = 0, \quad X_{4,2,2} = 0, \\ X_{4,2} + X_{4,2,2} + X_{4,2,3} = 1. \end{array}$$

The third example: not direct trains are dispatched but trains made up of the flows 4.2 and 4.1; here the following conditions are given:

$$X_{4,2,3} = 1 \Rightarrow \begin{array}{l} X_{4,2} = 0, \quad X_{4,2,2} = 1, \\ X_{4,2} + X_{4,2,2} + X_{4,2,3} = 1. \end{array}$$

The fourth example: gathering trains are introduced, the following conditions are given:

$$X_{4,2,3} = 1 \Rightarrow \begin{array}{l} X_{4,2} = 0, \quad X_{4,2,2} = 1, \\ X_{4,2} + X_{4,2,2} + X_{4,2,3} = 2. \end{array}$$

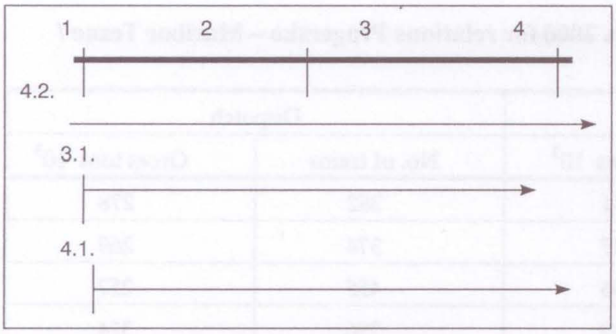

Figure 1 - Flows of freight

On the grounds of this example general condition for flow of freight in example 4.2. can be presented:

$$X_{4,2}+X_{4,2,2}+X_{4,2,3}\geq 1.$$

Following the same principle, conditions can be set for any flow of freight that is transited to more than one destination. These conditions are:

$$X_{ij}+\sum_{k=i-j}^{i-1} X_{ijk}\geq 1$$

$$i=4,5,\ldots,n;\quad j=2,3,\ldots,(i-2);$$
$$k=(i-j),(i-j+1),\ldots,(i-1).$$

The optimal flows of freight are analysed for all four stations. The research of technologies of shunting structure in the railway traffic is directed towards the flows of freight in the railway. Based on the results of flow gross, a graphic presentation of a possible solution of flows of freight for the railway station Maribor-Tezno was made. The flows of freight appear as receipt, dispatch and transit of freight at all the analysed stations.

3. SYSTEM APPROACH TO OPTIMISATION OF FLOWS OF FREIGHT

The existing system of the railway transport is very complex and complicated. It consists of various sub-systems which form the entire functioning of the basic system. There are various criteria that enable the deterministic and stochastic processes to take place. Therefore, they often cannot be studied in their real form. In such cases an adequate model of solving the problem is arranged if there is the need to change the system in order to improve its quality.

The research showed that the flows of freight can be classified as sub-system of freight transport. Therefore, the flows of freight have to provide their own structure for the system functioning. In the given example, the structure consists of all the elements vertically, in the same way as in the railway system, since the flows originate in the railway system. Horizontally, the flows can be split into separate sections of a certain line. In separate rail sections the lading can be established according to the number of trains as well as considering the quantity of the transported freight in gross and in net weight. The flows of freight of the station Maribor–Tezno are shown in Tables 1, 2 and 3 and in Figure 2.

An adequate model for solving the problem of shunting technology on the basis of the system structure is a contribution to new scientific statements as fundament for concrete solutions and it enables further research in order to improve the technology of the railway system. In order to create the model, the re-

Table 1: Flows of freight in receipt / dispatch in the year 2001 for relations Austria – Maribor-Tezno / Maribor-Tezno – Austria

	Receipt		Dispatch	
Month	No. of trains	Gross tons 10^3	No. of trains	Gross tons 10^3
January	320	233	319	225
February	324	237	338	225
March	385	313	381	270
April	340	272	333	244
May	359	276	346	246
June	367	285	354	252
July	353	281	320	275
August	228	154	206	243
September	241	180	232	259
October	359	294	346	255
November	386	313	346	255
December	318	250	309	231
Total	3980	3088	3830	3080

Table 2: Flows of freight in receipt / dispatch in the years 2000 for relations Pragersko – Maribor Tezno / Maribor Tezno – Pragersko

Month	Receipt No.of trains	Gross tons 10^3	Dispatch No. of trains	Gross tons 10^3
January	348	241	382	278
February	344	237	374	269
March	406	296	455	257
April	364	272	396	314
May	388	271	415	327
June	408	280	435	339
July	359	252	410	326
August	298	186	298	221
September	301	196	333	249
October	410	296	433	352
November	399	293	443	375
December	359	264	378	308
Total	4384	3084	4752	3715

Table 3: Flows of freight in receipt/ dispatch in the years 2000 for relations Prevalje – Maribor Tezno / Maribor Tezno – Prevalje

Month	Receipt No. of trains	Gross tons 10^3	Dispatch No. of trains	Gross tons 10^3
January	39	9	39	5
February	35	13	36	11
March	44	24	44	16
April	38	15	38	13
May	43	17	43	15
June	38	18	38	15
July	38	17	38	13
August	33	15	33	12
September	37	17	37	12
October	31	17	30	14
November	33	17	33	13
December	29	16	29	11
Total	403	204	438	150

sults of the research and the existing models for large systems were applied. Also, the amount of performed work stated in the research was taken into account.

3.1. Information flow in the system structure

The analysis results established numerous identified relevant factors that reduce effective work of the railways. These factors are:

- cost of transport,
- too many technical stations,
- uneconomical transport,
- uneconomical use of means of transport,
- low speed of freight transport, and
- uneconomical use of infrastructure capacities.

Using the cognition process a model can be introduced for solving problems of shunting technology on

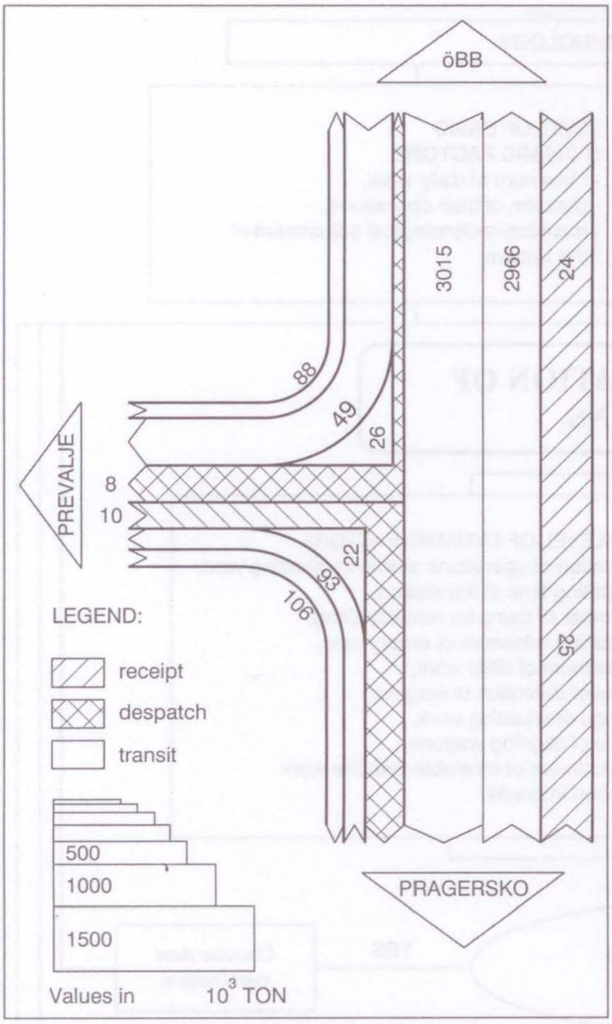

Figure 2 - Diagram of flows of freight of the station Maribor–Tezno.

the basis of system structure. The system structure in railway transport consists of the following levels:

1. Level of technical criteria which include all the elements that provide safe and regular railway transport.
2. Level of technological criteria which include all the elements that are used for implementation of the railway transport.
3. Level of organisational criteria including all the elements that secure the organisational functioning of the system.

Each level has to be analysed separately. The analysis shows that all three levels can be divided into two basic levels, i.e.:

1. DYNAMIC LEVEL or dynamic criteria,
2. LEVEL OF SYSTEM CAPACITY or capacity criteria.

The new method of level classification of individual set of criteria that influence technology of work in the railway transport has to be analysed in order to establish the interdependence of criteria which leads to homogenous functioning of the system and therefore to integral problem solving. Having determined the interdependence of the criteria, a new sub-system in the structure of shunting technology is defined in order to simplify the creation of a model of shunting technology in the railway transport. There are now two elements in the structure that are interdependent with information flow between them.

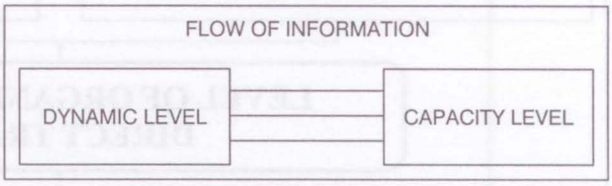

Figure 3 - Level of information flow

The dynamic level criteria are:

- time of detention of wagons,
- range of shunting work,
- time of alignment of wagons,
- arrivals of trains at the station,
- elements of timetables,
- speed of trains,
- circling time of wagons,
- circling time of engines,
- station intervals,
- intermediate station intervals,
- organisation of direct trains and
- duration of technical operations.

The capacity level or criteria are:

- number of marshalling yards in the system,
- dimensioning of marshalling yards,
- dimensioning of the receiving group of rails,
- dimensioning of the shunting group of rails,
- dimensioning of the dispatching group of rails,
- dimensioning other rail facilities and objects,
- number of wagons for re-marshalling,
- number of wagons without re-marshalling, and
- the shunting tasks of the station.

For the rationalisation of the system it will be supposed that in the network system not all the trains are shunted, which means that direct trains have priority in introduction. Direct trains are trains without re-marshalling at technical stations and the introduction of direct trains means gaining the time of detention of the wagons which results directly in the reduction of costs.

4. MODEL OF SHUNTING TECHNOLOGY

By means of dynamic and capacity levels a model will be created in order to search for the optimum of

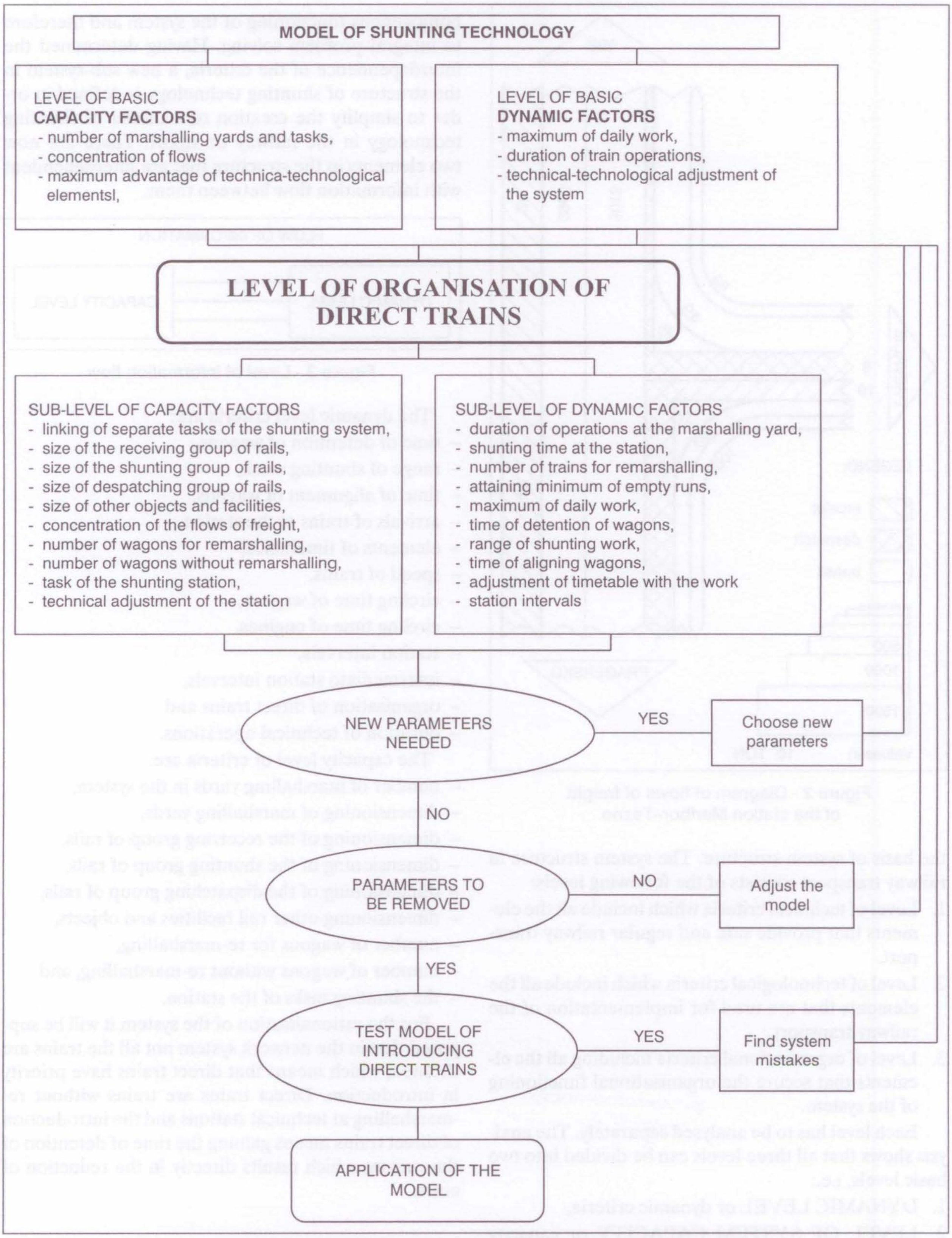

Figure 4 - Block diagram of the shunting technology model

the operation technology at the marshalling yards. The hypothesis will be thus confirmed that by means of logistic thinking a shunting model for small railway systems can be created (based on the existing models for large systems). This model enables us to attain the objective, namely to reduce the effect of the identified deterioration factors and thus improve the existing technology of work at the railway.

5. CONCLUSION

Since the plan of dividing the shunting operations differs and depends on the wagon flows, the organisation of wagon flows and the capacity of the marshalling yard are interdependent. This can serve as the basis for dimensioning optimal capacity of the railway network shunting system. Apart from other factors, the most important are the knowledge of time of the detention of wagons and time of re-marshalling of train formations. As far as conditions of the new concept of technology of work are concerned, there is a change in the indicators of work that affect the process of alignment of wagons. These indicators can be divided into two basic groups or two technological units. Their effect appears as large irregularities in the organisation of freight transport. In the area of technology of work at marshalling yards three basic technological levels also have to be considered: the preparation, the main and the final part of shunting. These levels include: receiving of train in the receiving group of rails, splitting of train and alignment of wagons into a new train formation in the shunting group of rails and in the dispatching group of rails.

In order to optimise the shunting work and thus also to optimise the wagon flows, the following needs to be considered: the concentration of flows of economy commodities and in this way reducing the number of dispatching stations and destinations with the objective of aligning direct trains that would provide such commercial speed that would be competitive to the road commercial speed. In this way we would gain reduction in detention of wagons at stations.

According to the research results and taking into consideration the problem of the extensiveness of the treated subject, it is obvious that further research is needed in order to meet the objective of permanent improvement of technology and organisation of railway transport in accordance with the whole transport system. In this respect, the optimisation of dimensioning of railway capacities, especially the placement of the marshalling yards is very important for the optimisation of transport and logistic activities. And this is where the theory of the railway transport system can effectively be applied.

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POVZETEK

MODEL TEHNOLOGIJE RANŽIRANJA NA OSNOVI STRUKTURE SISTEMA

Železniški promet se pojavlja v velikih težavah glede likvidnosti. Prav tako je majhnih sistemih velik problem zadrževanje vagonov na posameznih ranžirnih postajah, saj to podaljšuje čas potovanja tovora. V izogib temu je potrebno, da se raziščejo posamezni parametri, ki bodo omogočili postavitev takšnega modela tehnologije, ki bo zagotavljal zmanjšanje čakanja vagonov na postajah kakor tudi optimiranje števila ranžirnih železniških postaj za male sisteme. To nam med drugim tudi omogoča iskanje zveze med ranžirnim delom v železniškim prometom in uporabo teorije sistemskega pristopa, ki pomeni aktualen znanstveni problem. V klasični tehnologiji se delo ranžiranje opravlja brez upoštevanja in uporabe sistemskega pristopa. Pri novih sistemih ranžiranja v železniškem prometu pa je nujnost upoštevanja teorije prometnih sistemov kot nadgradnjo klasičnih metod.

Kot je že poudarjeno, bo z vidika teorije napravljen pomemben prispevek za uporabo teorije sistemov v ranžirne namene, saj predlagan model uspešno omogoča členitev posameznih elementov v strukturi železniškega prometa v celovito delovanje ranžiranja na železniških postajah.

KLJUČNE BESEDE

tehnologija, ranžiranje, železnica, sistem, struktura, optimiranje

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