ANTON PEPEVNIK, D.Sc.
Fakulteta za pomorstvo in promet
Pot pomorščakov 4, 6320 Portorož, Republika Slovenija
E-mail: anton.pepevnik@guest.arnes.si
BLAŽ BOGOVIĆ, D.Sc.
Fakultet prometnih znanosti
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
E-mail: blaz.bogovic@fpz.hr

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THE RAILWAY TRAFFIC SHUNTING SYSTEM

ABSTRACT

Economy demands quality performance of transport services from all spheres of the traffic system. The shunting system in railway transport is a part of the traffic system. The fact that the railways are an organization of special social interest makes its organization structure the more important for the economic development. Problems that appear in the development of the economic system clearly point out numerous irregularities within the railways. The demand of quality transport services requires rationality of transport which consequently requires great changes in the field of traffic organization structure and exploitation of transport capacities.

Elementary parameters of the quality evaluation of the transport service in all traffic subsystems are: speed, safety and regularity of transport. The same parameters can be implemented as the basis of technical and exploitation characteristics of traffic.

The shunting system in railway traffic is affected by numerous elements which are interconnected and represent a uniform technological process. Subsequently, the shunting system is considered a uniform technological system. The characteristics of such a system are apparent in the technical and technological process, e.g.:

- *integrality, i. e. characteristic of collective production of transport services;*
- *homogeneity of transport means;*
- *standardization of means of integral transport.*

In the process of transport demands, maximum service quality is incessantly required. However, maximum quality with certain quantitative dimension in regard to mode, place and time of the transport process requires engagement of transport means, which directly affects the costs. Therefore, it can be asserted that the optimum lies between the maximum quantitative and qualitative dimensions of transport services and in the determined time of minimum costs of means.

KEY WORDS

shunting, hump, system, structure, transport

1. INTRODUCTION

Railway traffic is the classical example of a homogeneous system, which consists of numerous interconnected elements with the common goal, i.e. the organization of passenger and freight transport. According to the process operation the transport process can be dealt with separately for passenger transport and separately for freight transport.

Each connection among individual system and subsystem elements can be dealt with separately, as individual organization units. Such analysis can be carried out until the moment of initial technological operations or technology of work for individual transport services. The freight transport subsystem also consists of individual elements. The research deals with the railway traffic shunting system, in greater detail with shunting of freight wagons. Within the frame of freight transport system the following has to be distinguished:

- the process of initial-final operations,
- the process of direct freight transport,
- the shunting process.

At stations where technological handling is realized separately according to the shunting process, collective shunting work is performed, determined by the plan of train assembling. Interactivity is determined by freight trains timetable, which connects the work of all marshalling yards and shunting stations in the railway network.

Accordingly, the station technological processes have to be adjusted to the freight trains timetable. The timetable has to meet the demands of the users of railway services. The timetable is the basis for determination of tasks for all the freight depots in the railway network.

The shunting process in the marshalling yard is permanently affected by work performed in individual elements. It is also necessary to define the irregularity of work of individual elements in the frame of technological processes as the result of the environment influence on the system. For this reason, the large homogeneity of solving problems arising from shunting technology at stations can be discussed.

2. RAILWAY SHUNTING SYSTEM

Railway traffic shunting system consists of four elements that are connected and form the system whole. The elementary parts of the shunting system are determined on the basis of the number of marshalling yards and shunting stations with all the required elements in order to provide performance of technological processes, and with their mutual relations.

The basic task of marshalling yards in the frame of organization of freight transport in the railway network is assembling and splitting freight trains according to the shunting works in the traffic network. According to classification of separate groups of wagons, taking into account their direction of moving into the train formation, the heterogeneous incoming flow of wagon changes at stations into homogeneous outgoing flow of trains. The system outgoing flow is presented with direct trains, gathering trains and trains for industrial and port maintenance in the frame of railway network. Apart from local work, other tasks are performed at marshalling yards, which enable assembling of trains for larger distances according to plan, adjusted to the timetable; and work performed on transit trains, e.g.: change of the engine and personnel, technical control of the train, adding individual groups of wagons etc.

The fact that all the freight trains are assembled in the marshalling yards, apart from those directly aimed at recipients, leads to the conclusion that marshalling yards have a highly important role in the performance of freight transport in the railway network. In marshalling yards the changes are performed with regard to wagon flows on the basis of splitting and assembling new train formations.

Connection among individual marshalling yards as basic elements of the railway network shunting system is created by correspondent wagon flows. This means that the physical dimension of the shunting system is determined by stations with the task of receiving and dispatching wagon flows, loaded and unloaded freight wagons.

2.1. Optimum regime of shunting system operation

The existing researches established that the planning of shunting work is multilayered. Marshalling yards appear in the railway system network as a network of system of mass wagon flows. In accordance with the operation of marshalling yards, various mass wagon flows can be anticipated in the network complex: train handling in the reception sidings in order to prepare wagons for splitting and final assembling; train handling in order to prepare the train for dispatch; and, dispatch of trains from stations. Individual tasks depend on the number of maintenance channels which can be divided into several parallel maintenance systems.

The function includes the correspondence of wagon flows and numerous factors of individual stations, i. e.:

- quantity of shunting work and employment of shunting capacities,
- detention time of wagons,
- wagons gathering time at the station,
- costs of the shunting work.

The wagon flows for the next timetable period have to be planned on grounds of the established wagon flows and requirements in the previous period. The basis for establishing wagon flows can be the waybill as a consignment document of the wagon and as appropriate for handling.

The fundamental goal of shunting at the marshalling yards is the assembling and splitting of train formations. Therefore, the shunting work is the most important part of the work technology at marshalling yards. Rationalization of shunting work can establish station shunting ability and other numerous work indicators.

The indicators of shunting work at stations, according to the exploitation of shunting capacities, are:

- the number of marshalled wagons according to the structure of flows,
- frequency of wagon flow dispatch,
- the number of dispatches for stations for which the marshalling yard performs marshalling of train formations, for domestic and international traffic.

The number of dispatches for individual stations for which the trains are marshalled as well as the frequency of wagon flows depend on the location and tasks of the marshalling yards in the railway system. Beside trains split in the marshalling yards, trains in transit arrive at the stations. Therefore, certain tasks for further journey of transit trains also have to be performed. If the personnel performing work at trains for marshalling also perform work at transit trains, the task is not excluded from other tasks into a separate system, but it remains part of the common system. Time of detention of wagons at the station is thus shortened, especially on commercial receiving of the train. If separate work groups of personnel perform tasks on transit trains and others handle trains in the marshalling yard, then the function has to be separated into separate systems.

The system network of mass operation which represents the system operation of the belonging stations with track sections and marshalling yard under the conditions of continuous splitting of trains on the hump, can appear as presented in Figure 1.

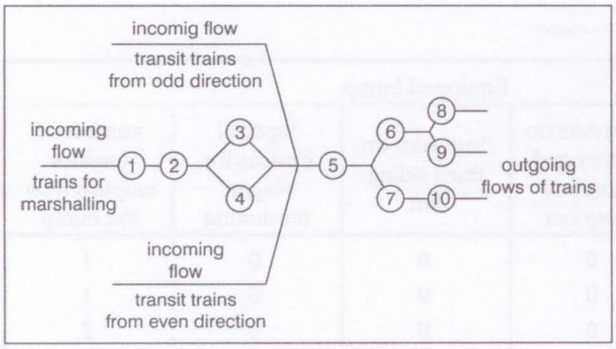

Figure 1 - Service system network

- System 1 – incoming route sections – reception sidings or IRS – RS;
- system 2 – reception sidings – hump or RS – H;
- Systems 3 and 4 – sorting sidings. In this group as many systems are known as there are shunting engines or shunting areas. In this example two shunting engines were employed, therefore there are two systems;
- System 5 – departure sidings - DS;
- Systems 6 and 7 – providing a working engine. There are two systems in this example since an electric and a diesel locomotive have to be available;
- Systems 8, 9 and 10 – departure sidings – outgoing route sections or DS – ORS.

In this example three route sections are known since there are three systems. Each system has to be separately dealt with since in each system detention time of wagons for commercial and partly also technical control of train formations can be shortened.

Taking into account the mentioned facts and presentation of work at the station, and regarding the modern capacities, the marshalling yard Zalog has been treated as an example of wagon flows in the Slovenian Railways network. Above all, the extent of marshalling yard has to be considered. It is known that detention of wagons at marshalling yards requires certain time for splitting and assembling of new train formations. Splitting and assembling train formations is performed at bigger marshalling yards over the shunting hump. In this respect, the hump is of great importance when deciding about the tasks of individual stations and all the stations of the Slovenian Railways.

3. SIGNIFICANCE OF THE HUMP IN THE SHUNTING SYSTEM

The marshalling yard Zalog, situated on the route Ljubljana - Zidani Most, is schematically presented in Figure 2.

It has three separated successive groups of sidings for the following purposes:

- reception sidings (**RS**) are intended for receiving trains;
- sorting sidings (**SS**), are intended for assembling and splitting of train formations over the automated hump;
- departure sidings (**DS**), where final operations before the departure of trains are performed; and
- next to departure sidings there are additional sidings for transit trains which do not change formation (TT – transit trains).

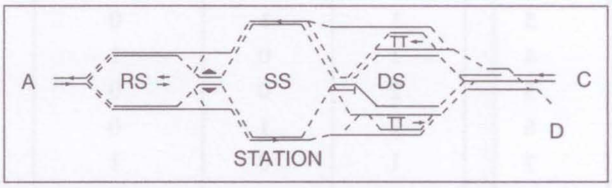

Figure 2 - Scheme of sidings at the marshalling yard Zalog

All the trains that are split at a certain marshalling yard represent a uniform incoming flow and are received in the reception sidings for system handling and preparation of splitting. The elements of this system are divided into three basic groups: general system elements, concrete system elements for each individual example, and the system type.

General system elements include the following subgroups: incoming flow, detention lines, maintenance channels and outgoing flows. The concrete system elements for each individual example include a great number of tasks, derived from the general part of the system: incoming flow – a number of elements of arrival of the train in the reception sidings for all the trains that are being split; detention lines – consisting of train formations waiting for the beginning of handling in reception sidings; maintenance channels – groups of personnel performing technical and commercial controls, preparation of the train for marshalling and handling of documentation; outgoing flows – a great number of elements of final handling of the train prepared for splitting. The system type is determined according to concrete system elements. Since handling of train formations is performed simultaneously by various groups of personnel, it can be established that this type of the system is a multi-channel system. However, all activities can be performed simultaneously, and the multi-channel system can be remodelled into a single-channel system.

3.1. Function of the hump

The second system element are the reception sidings which are connected with the hump. Train formations are marshalled in the reception sidings for further operations, mainly due to train splitting over the hump. It can be concluded that reception sidings and

Table 1 - Hump technical device equipment

Number of variants	Siding number on the hump	*diversion siding	Equipped hump				
			*centrally operated points with automatic track setting	*retarders on primary and secondary siding fan	*retarder on third siding fan	*special devices for wagon tensioning	number of engines employed on the hump
0	1	0	0	0	0	0	1
1	1	0	1	0	0	0	1
2	1	0	0	0	0	0	2
3	1	1	0	0	0	0	2
4	1	0	1	1	0	0	1
5	2	0	0	0	0	0	2
6	2	1	0	0	0	0	2
7	1	0	1	0	0	0	2
8	1	1	1	0	0	0	2
9	1	0	1	1	1	0	1
10	2	0	1	0	0	0	2
11	2	1	1	0	0	0	2
12	1	0	1	1	0	0	2
13	1	1	1	1	0	0	2
14	1	0	1	1	1	1	1
15	1	0	1	1	1	0	2
16	2	0	1	1	0	0	2
17	2	1	1	1	0	0	2
18	1	1	1	1	1	0	2
19	2	0	1	1	1	0	2
20	1	0	1	1	1	1	2
21	2	1	1	1	1	0	2
22	1	1	1	1	1	1	2
23	2	0	1	1	1	1	2
24	2	1	1	1	1	1	2
25	2	0	1	1	1	1	3
26	2	1	1	1	1	1	3

"0" means that hump is not equipped with this technical device.
"1" means that the hump is equipped with this technical device.

the hump are presented as two successive maintenance systems, i.e.: system 1 – incoming sections – reception sidings; system 2 – reception sidings – the hump.

The capacity of the marshalling yards depends to a great extent on the capacity of the hump, since each wagon passes over it with exception of those in transit trains. With great certainty it can be claimed that the hump is a bottleneck of every marshalling yard. The hump capacity and therefore the capacity of the marshalling yard have to correspond to the number of wagons that the yard is about to handle. It is also clear that capacity depends on the level of development, technical equipment and implemented technology of work and that it is constant in time intervals between two changes – modernizations. Each modernization is defined by investment costs and exploitation.

On the other hand, capacity demands change with the time, as a rule they grow. Frequently, a problem appears related to the precedence of modernization, or time for introduction of a selected measure and length of modernization stage. As a rule, longer time space is considered, and the first step is the reduction of common discount investment and exploitation costs. Possible measures for raising the hump capacity are:

- introduction of the second shunting engine,
- building of the second siding over the hump,
- building of diversion siding between shunting and reception sidings,

- central and automated operation of shunting tracks,
- providing in-built retarders on primary and secondary siding fans,
- third level of braking, i.e. providing in-built retarders also on the third siding fan,
- special devices for pushing wagons after descent, and
- introduction of the third shunting engine for work on the hump.

With help of logical technological combinations these measures can result in 26 variants of various hump capacities.

3.2. Hump capacity

For each variant of stage development of the hump, capacity is calculated with help of the formula:

$$n_V = \frac{1440}{t_i^b\left(1+\frac{T_{pr}}{1440-T_{pr}}\right)}$$

Technological interval of the hump depends on the hump equipment and on the number of engines that handle trains over the hump.

The number of trains, marshalled in this marshalling yard can be expressed with the function:

$$n(t)=n(1)(1+i)^{t-1}$$

The perspective dimension of work can also be expressed with another function, e.g.:

$$F(t)=Q_t\{x(t-1);x(t)\}+F(t-1)$$

or with the system of equations which define the optimum values of criteria functions according to the years and periods of observation:

$$F(1)=\min_{u(1)}\{Q_1[x(0);x(1)]\}$$

$$F(2)=\min_{u(t)}\{Q_2[x(1);x(2)]+F(1)\}$$

....

$$F(t)=\min_{u(T)}\{Q_t[x(t-1);x(t)]+F(t-1)\}$$

....

$$F(T)=\min_{u(T)}\{Q_T[x(T-1);x(T)]+F(T-1)\}$$

The equation has to be solved starting with the first year of observation period. In the first year the optimum solution is taken into consideration, that is, the minimum function value of changing from state x(0) into state x(1). With each following step the sum of conditional optimum solutions of the current and previous step is taken into account. The minimum value F(T) in the last year of observation period defines the optimal strategy of marshalling yard development.

3.3. Optimization of the hump development

The criteria for optimization of station development are common discounted investment and exploitation costs which can be expressed with the formula:

$$F=\sum_{t=1}^{T}\frac{I(t)}{(1+1)^t}+\sum_{t=1}^{T}\sum_{t-1}^{t}\frac{T_e(t)}{(1-i)^t}\to \text{minimum},$$

To simplify the model, it is assumed that the null, i. e. the starting variant is a double track hump with manual track setting and with work of one shunting group. Measures for improving hump capacities will be formed into groups of the following simplifications:

- introduction of the second shunting engine,
- centrally operated points on the shunting track,
- providing in-built retarders in primary and secondary siding fans,
- providing in-built retarders in the third siding fan.

For this simplified example of the hump stage development the variants are presented in Tables 2 and 3.

Variants of stage hump development could be presented graphically; however, due to extensiveness of possible variants the observation time will be limited to three years and three variants of improving capacities.

The starting or null year is determined by null variant of development with its function of costs F = Q. In the first year t = 1 it can remain at the null variant or it can progress to the first, second, ..., up to the seventh variant (as presented in the table in the first row). At that point functions of progress from the null variant into all the rest of variants have to be calculated, i.e.: $Q_{0,0}^{(1)}$ $Q_{0,1}^{(1)}$ $Q_{0,1}^{(1)}$ $Q_{0,3}^{(1)}$. The function of progress is presented by common discount investment and exploitation costs.

The function of criteria of the first year for each variant of development is $F_{t=1,j}$ $F_{1,0}=Q_{0,0}^{(1)}$ $F_{1,1}=Q_{0,1}^{(1)}$ $F_{1,2}=Q_{0,2}^{(1)}$ $F_{1,3}=Q_{0,3}^{(1)}$ or in general: $F_{1,j}=Q_{0,j}^{(1)}$

In the second year, t = 2, possible variants of development for each progress point $Q_{w,j}^{(2)}$; $Q_{0,0}^{(2)}$; $Q_{0,1}^{(2)}$; $Q_{1,1}^{(2)}$; $Q_{0,2}^{(2)}$; $Q_{1,2}^{(2)}$; $Q_{2,2}^{(2)}$; $Q_{0,3}^{(2)}$; $Q_{1,3}^{(2)}$; $Q_{2,3}^{(2)}$; $Q_{3,3}^{(2)}$; have to be determined, followed by determination of conditional optimums with the formula:

$$F_{i,j}=\min Q_{w,j}^{(t)}+F_{t-1,w}$$

or with the formulas:

$$F_{2,0}=Q_{0,0}^{(2)}+F_{1,0}$$

$$F_{2,1}=\min\{Q_{0,1}^{(2)}+F_{1,0};\ Q_{1,1}^{(2)}+F_{1,1}\}$$

$$F_{2,2}=\min\{Q_{0,2}^{(2)}+F_{1,0};\ Q_{1,2}^{(2)}+F_{1,1};\ Q_{2,2}^{(2)}+F_{1,2}\}$$

Table 2 - Variant of a simplified model of the hump stage development

Equipped hump				
Running number of variant	Number of manoeuvre engines	Central operation of tracks	Retarders in primary and secondary siding fans	Retarders in third siding fan and devices for wagon tensioning
0	1	0	0	0
1	1	1	0	0
2	1	1	1	0
3	1	1	1	1
4	2	0	0	0
5	2	1	0	0
6	2	1	1	0
7	2	1	1	1

Table 3 - Matrix of logical successive changes of hump development

j / w	0	1	2	3	4	5	6	7
0	1	1	1	1	1	1	1	1
1	0	1	1	1	1	1	1	1
2	0	0	1	1	0	0	1	1
3	0	0	0	1	0	0	0	1
4	0	0	0	0	1	1	1	1
5	0	0	0	0	0	1	0	1
6	0	0	0	0	0	0	1	1
7	0	0	0	0	0	0	0	1

$$F_{2,3} = \min\{Q_{0,3}^{(2)} + F_{1,0};\ Q_{1,3}^{(2)} + F_{1,1};\ Q_{2,3}^{(2)} + F_{1,2};\ Q_{3,3}^{(2)} + F_{1,3}\}$$

Further progress, to the third year, is calculated in analogy to the previous formulas, or:

$$F_{3,0} = Q_{0,0}^{(3)} + F_{3,0}$$

$$F_{3,1} = \min\{Q_{0,1}^{(3)} + F_{2,0};\ Q_{1,1}^{(3)} + F_{2,1}\}$$

$$F_{3,2} = \min\{Q_{0,2}^{(3)} + F_{2,0};\ Q_{1,2}^{(3)} + F_{2,1};\ Q_{2,2}^{(3)} + F_{2,2}\}$$

$$F_{3,3} = \min\{Q_{0,3}^{(3)} + F_{2,0};\ Q_{1,3}^{(3)} + F_{2,1};\ Q_{3,3}^{(3)} + F_{2,2};\ Q_{3,3}^{(3)} + F_{2,3}\}$$

The minimum value of the function $F_{3,j}$, under the condition that it corresponds to the demanded range of work in optimal conditions of operation at each stage of development, represents optimum strategy of hump development and development of the marshalling yard. The optimum condition is gained in retroactive way from the variant with minimum value of the function of criteria $F_{3,j}$ back to the null variant in the null year.

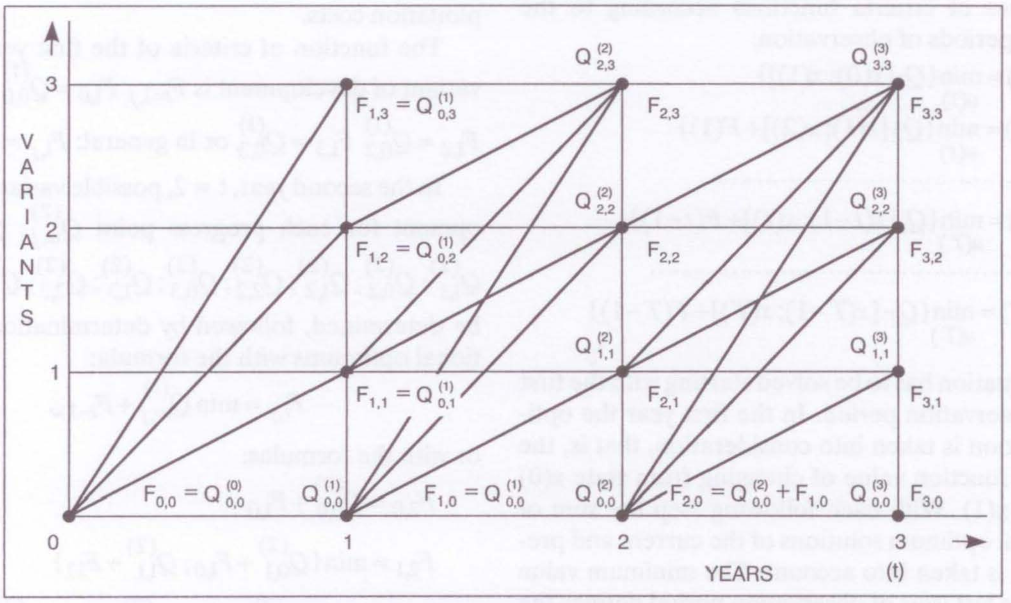

Figure 3 - Simplified scheme of variants of hump stage development

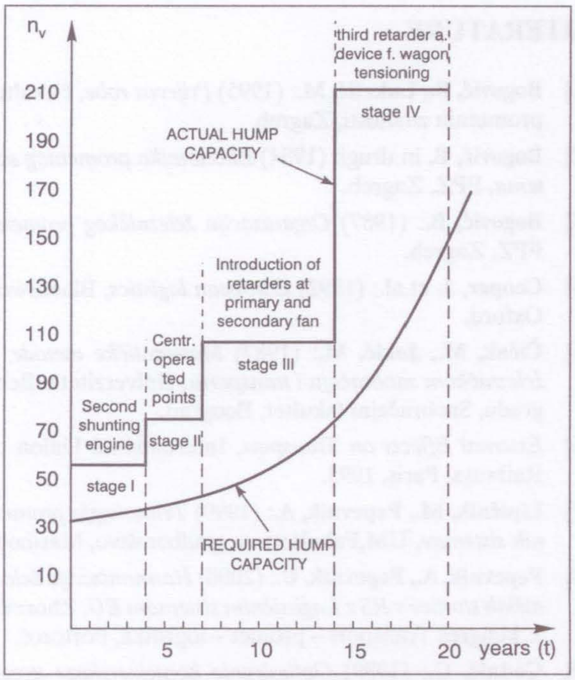

Figure 4 - Example of optimum relation between the required and actual hump capacity

Due to the large number of possible variants for an observation period of 20 to 30 years there is no possibility to solve the problem manually.

Figure 4 presents an example of a hump stage development with dynamic programming so that the actual capacity is always above the required one, and there are no standstills in the station operation due to the bottlenecks that could be caused by the hump.

The outgoing flow from stage 1 is at the same time the incoming flow into stage 2. The intensity of flow is:

$$\lambda = \frac{N_r}{24}$$

The changing coefficient of the interval ν_{iz} can be determined only on the grounds of recording in the field. All the elements appearing in the second stage can be arranged into general stage elements, into concrete stage elements and into stage types. The general stage elements include: the incoming flows, the lines, the maintaining channel and the outgoing flow. The concrete stage elements include: a large number of elements that belong to the final preparation of the train for splitting, the outgoing flow from stage 1, which is at the same time the incoming element into stage 2; the line consists of the marshalled train groups waiting to be split; the hump; a large number of elements of finalization of train splitting. Regardless of the number of shunting engines employed in the hump, the system is single-channelled if the trains are split successively. The system can turn into a double-channel system only provided that a double track hump is available and the splitting of train formations can be performed on both tracks.

4. CONCLUSION

In this system it is necessary to determine the optimum number of engines and shunting personnel, for the existing conditions of exploitation of stable devices, i.e. rail devices on the hump and their equipment according to work conditions. These conditions are result of the minimum goal functions or common costs, which consist of the costs for wagon detention in the system, the costs of shunting engines including the costs of fuel, and costs of shunting personnel.

The technological process of splitting and assembling train formations is a uniform and homogeneous system. Nevertheless, the final assembling of train formations has to be performed in the departure sidings. The final train formation is performed with help of a shunting engine which runs on departure sidings and on sorting sidings. The number of shunting engines depends on the number of trains that have to be formed and from the work division of the final operations.

If shunting areas are defined and introduced, and at the same time the work of shunting engines on departure sidings for assembling trains is specialized, we get several single-channel systems of mass maintenance. The elements of the system of shunting rolling stock and departure sidings for assembling train formations include: general system elements, concrete system elements and system types. The general elements include the incoming flow, the line, the maintenance channels and the outgoing flow of trains. The concrete elements include an upgrade of the general elements. This group includes: a large number of final works in sorting sidings according to gathering wagons for train formation; assembled trains waiting for final operations; shunting platform and shunting engine and a large number of tasks in order to service the assembled trains from the sorting sidings to the departure sidings. The implementation of a single-track hump represents a single-channel system type.

ANTON PEPEVNIK, D.Sc.
Fakulteta za pomorstvo in promet
Pot pomorščakov 4, 6320 Portorož, Republika Slovenija
E-mail: anton.pepevnik@guest.arnes.si
BLAŽ BOGOVIĆ, D.Sc.
Fakultet prometnih znanosti
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
E-mail: blaz.bogovic@fpz.hr

POVZETEK

SISTEM RANŽIRANJA V ŽELEZNIŠKEM PROMETU

Gospodarstvo zahteva kvalitetno opravljanje transportnih storitev od vseh dejavnikov prometnega sistema. V sklopu prometnega sistema je tudi sistem ranžiranja v železniškem prometu. Glede na to, da železnica predstavlja organizacijo, ki je

posebnega družbenega pomena, je njena organiziranost toliko pomembnejša za razvoj gospodarstva. Problemi, ki se pojavljajo v razvoju gospodarskega sistema, jasno pokažejo številne nepravilnosti znotraj same železnice. Zahteva po kvalitetni transportni storitvi temelji na principu racionalnosti transporta, kar zahteva velike spremembe na področju organizacije prometa in izrabe transportnih kapacitet.

Kot osnovni parametri ocenjevanja kvalitete prevozne storitve v vseh prometnih podsistemih so: hitrost, varnost in rednost prevoza. Omenjeni parametri se lahko uporabijo tudi kot osnova tehnično-eksploatacijskih značilnostih prometa.

Sistem ranžiranja v železniškem prometu je pogojen s številnimi elementi, ki so medsebojno povezani in predstavljajo enovit tehnološki proces. Na osnovi tega lahko zaključimo, da se tudi ranžirni sistem smatra kot enovit tehnološki sistem.

Takšno značilnost sistema predstavljata predvsem tehnični in tehnološki proces, kot npr.:

- *integralnost, t. j. značilnost skupne proizvodnje transportne storitve;*
- *homogenost transportnih sredstev;*
- *standardizacija sredstev integralnega transporta.*

V procesu transportnega povpraševanja se neprestano zahteva maksimalna kvaliteta storitve. Z druge strani zahteva maksimalna kvaliteta z določeno kvantitativno dimenzijo glede na način, kraj in čas transportnega procesa večje ali manjše angažiranje transportnih sredstev, kar predstavlja direktni vpliv na višino stroškov. Zaradi tega lahko trdimo, da se optimum nahaja med maksimalno kvantitativno in kvalitetno dimenzijo transportne storitve in v določenem času minimalnega stroška sredstev.

KLJUČNE BESEDE

ranžiranje, drča, sistem, struktura, transport

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