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Failure-free operation of classification yards through technology optimization

The railway operation practice has proved that the condition of technical equipment considerably influences the processes of traffic organization and making-up/breaking-up trains. Operational failures lead to a lower estimated capacity of sorting facilities and, consequently, to a lower carrying capacity of stations and sections. Besides, they inflict losses on both Ukrzaliznytsia and wagon/freight owners, thus affecting train and wagon flows. The objective of the study is to analyze the influence of failures in sorting facilities on their estimated capacity and to search for ways to minimize their negative impact. Methodology of the study is computational simulation and graphical interpretation of a 24-hour estimated capacity of the sorting hump and the lead track, the most significant parameters of which are weight average values, and a variable parameter is the failure rate for technical equipment.

Keywords: classification yard equipment, capacity, technique, failures, permanent way.

The State Goal-Oriented Programmer on the Rail Transport Reforms proposes reduction in transportation cost with efficient use of transport infrastructure [11]. So that to achieve the target while restructuring Ukrainian Railways there is a need to develop a technological and economic approach to the freight transportation management.

Therefore, the problem how to estimate the capacity of classification yard equipment is obviously urgent, and the solution is the basis for determining the qualitative operational parameters [13].

The railway operation practice demonstrates that the state of equipment considerably influences the freight and passenger traffic management. The failures which occur during operation cause lower capacity of the equipment resulting in lower traffic capacity of stations and routes. Besides, they yield losses for Ukrainian Railways, freight owners and train operators in terms of train and car flow traffic.

Subject matter of the study

The classification, freight and sectional stations are equipped with humps of high, average or low capacity, sorting yards and lead tracks.

The classification yard is designed as a complex technological system which comprises not only the track layout with an artificial elevation of the rail track section for sorting cars and application of gravity force at falling gradients for sorting humps and lead tracks, but also shunting locomotives, technical equipment, repair facilities, maintenance buildings with utilities, lighting facilities, motor roads, crossovers, tunnels, passages for electric and motor trucks [3].

The track layout elements at classification yards (humping tracks, hump neck, classification tracks, bypass sidings, lead tracks) are designed with consideration of their periodical partial closures for capital, mid-life and other scheduled track repair works.

The development of new or refurbishment of existing classification yards require analysis of the maximum possible number of cars to be sorted in a specific time, i.e. a required capacity which takes into account station functions, features connected with its location within the rail network and industrial area. The required capacity of the main sorting unit is determined on the base of the forecasted average daily volume of operation, established by economic studies for calculated operation periods.

Thus, the subject matter of the study is the scheduled breaking-up of freight trains on rail classification facilities with their consequent making-up. The scope of the study is the support of capacity of the classification facilities with the optimized technical equipment.

Purpose

The objective of the study is minimization of failures in the signaling and interlocking devices used for regulation, daily non-stop rail operations and compliance with the capacity standards for classification facilities while observing the safety regulations during shunting operations.

In order to achieve the assigned objective the authors suggest:

- ◆ presenting the relation between the number of cars to be sorted at the classification yard within a specified time and the failures in technical equipment of the classification yard;
- ◆ explaining causes of failures in the technical equipment of the classification yard;
- ◆ demonstrating possibility to minimize a negative impact of these causes in the technical equipment of the classification yard;
- ◆ proposing solutions to minimize the causes of failures in the signaling and interlocking devices by eliminating their impact on the classification yard capacity.

Literature data analysis

Improvements to the classification yard capacity are in the focus of numerous publications, and the following efficient solutions have been proposed:

- ◆ extension of lead tracks for placing the whole train consist on them, which allows decreasing a hump technological interval and increasing the hump capacity [6];
- ◆ use of the parameters of maximum, minimum and technical shunting speed; researches into methods to increase the sorting hump capacity through distribution of shunting work between the hump neck and exit neck of the classification yard have been conducted; dependencies which allow determining the moment when shunting work should be transferred to another shunting site of the classification yard, and also the freight volumes when technical equipment of the classification yard should be increased have been obtained [2];
- ◆ implementation of the calculation method regarding the sorting hump capacity which considers dependency of the train shunting speed on separation of sets of wagons and the number of wagons requiring re-sorting because they have not been uncoupled on separating switches [4, 8];

- ♦ after studying the problem of the optimization and modeling of classification stations for several years, Chinese engineers have proposed: to improve the wagon bogie and to increase the axle loading from 20.5 to 25 tons, to increase the wagon length, to use the model of the optimal order of wagons pushing to the hump, to use an integrated dispatching model for optimal operations at sorting stations with implementation of a heuristic approach, to use a model and an algorithm of dynamic distribution of a wagon flow in uncertainty [14, 16, 21, 22];
- ♦ implementation of the YARDSIM method to estimate sorting humps in North America as a visual modelling instrument, though it cannot automatically solve the problem, but can be used for What-If analysis; a new Computer Aided System (CAD III) is under development in the USA and will include the automated car traffic planning using a target function based on optimization [15, 19];
- ♦ simulation of the classification station capacity by using the queueing theory for operation optimization, considering an additional possibility for more efficient deployment of staff and usage of classification complex capacities; reduction of a car servicing time is possible by operation modernization when using the RFID reader; these improvements can lead to operational cost reduction [20];
- ♦ grouped dangerous situations on subsystems and objects are selected in which dangerous failures can occur and the allocation of a generalized criterion - safe passage of the hooks [9].

Thus, judging by the analysis results one can conclude that previous studies have not pay enough attention to parameters which cause failures in technical equipment of classification yards and make scheduled sorting and shunting operations impossible. It can cause failures in the classification yard operation and in the operational planning. The main influence on the processing capacity hills with a break in her work. Reducing these breaks are important for increasing the daily processing capacity sorting slides [1].

Therefore, the study proposes the solution which will minimize failures in the signaling and interlocking devices preventing their impact on the classification yard capacity.

Methodology

For classification, freight and sectional stations the calculation of the daily sorting hump capacity according to [5] is defined by the formula:

$$N_h = \frac{\alpha_{conf}(1440 - \sum T_{reg})}{t_h \mu_{re-s}(1 + \rho_f)} m_{ave} + N_{reg} \quad (1)$$

where α_{conf} is the coefficient which considers possible breaks in hump operations due to conflicting routes;

$\sum T_{reg}$ is the time of regular operations not connected to the servicing of the main car traffic volume, min;

t_h is the average duration of a hump technological interval (considering the time for entering, pushing, shunting, making-up and backing), min;

μ_{re-s} is the coefficient considering the re-sorting of wagons due to congestion and insufficient track length;

m_{ave} is the average number of wagons in a consist;

N_{reg} is the number of broken-up wagons from repair sidings, wagons which change their direction, ones from the wagon depot, etc., which are shunted for the period $\sum T_{reg}$;

ρ_f is the coefficient which considers failures in technical devices. It is known from [7] that ρ_f for non-mechanized humps is taken 0.03. For other humps it is taken depending on the number of wagons in a consist, type of retarders and the duration of a hump technological interval.

The lead track capacity is defined according to the duration of its scheduled daily occupation, therefore the capacity is easily defined with the capacity factor:

$$N_{t.c} = \frac{n_{b.m.}}{K} \quad (2)$$

where $n_{b.m.}$ is the actual daily number of trains being broken-up and made-up on the lead track;

K is the capacity factor for the lead track

$$K = \frac{\mu_{res} T_{t.c.}}{1440 \alpha_{conf} - \sum T_{reg}^d} \quad (3)$$

where μ_{res} is the coefficient of resorting;

$\sum T_{reg}^d$ is the daily time when the lead track is occupied with regular operations independent on the volume (track maintenance, change of locomotive crews and the servicing of shunting locomotives, handling of certain number of assorted trains), min;

α_{conf} is the coefficient considering possible breaks in the lead track operations due to conflicting routes;

$T_{t.c.}$ is the total daily time when the lead track services trains, min.

The total time of the lead track occupation is

$$T_{t.c.} = \left[\sum n_b t_b + \sum n_m t_m + \sum n_m (t_{mov}^d + t_{ret}) + \sum n_{sh} t_{sh} \right] \times (1 + \rho_f) \quad (4)$$

where n_b is the daily number of consists being broken-up on the lead track;

t_b is the duration of breaking up the train, min;

n_m the daily number of consists being made up on the lead track;

t_m is the duration of making up the train, min;

t_{mov}^d the time spent on moving the wagons closer and transfer of the formed train to the departure track, min;

t_{ret} the time for the shunting locomotive to return to the lead track, min;

n_{sh} is the number of shunting and other movements along the lead track;

t_{sh} is the time when the lead track is occupied with shunting (train) movements, min;

ρ_f is the coefficient considering failures in technical devices.

By substituting (3) and (4) in (2) the resulting formula proposed by the authors [5] will be as follows

$$N_{t.c.} = \frac{n_{b.m.} (1440 \alpha_{conf} - \sum T_{reg}^d)}{\mu_{res} \left(\sum n_b t_b + \sum n_m t_m + \sum n_m (t_{mov}^d + t_{ret}) + \sum t_{sh} n_{sh} \right) \times (1 + \rho_f)} \quad (5)$$

The analysis of (1) and (6) shows that the capacities of a sorting hump and lead tracks are influenced by failures in technical equipment of the station. The station is considered as a complex dynamic system, reliability of which is defined by reliability of its elements. On the basis of functional features of each technical device of the system one can mention such elements: track, switches, locomotives, signaling and interlocking devices (electrical interlocking of signals and switches, car braking automation with retarders, switch automatic interlocking in the hump yard, automatic braking), electrical supply facilities on electrified lines.

The failures in electric interlocking devices include:

- ♦ stops: when one of the switches of any insulated section fails, movements and use of the other switches on this insulated track section are impossible till the causes are found out;
- ♦ decreased speed of the traffic flow;
- ♦ breaks in traffic of trains, shunting movements, shunting from the hump.

Thus, failures in the signaling and interlocking devices cause forced stops and limit the daily classification yard capacity. Refuse the more, the more time they are a tense, working state [1].

The time, when the failure in the switch is eliminated, can be determined from the moment the failure occurs till the moment the switch starts to operate automatically, manually or electric interlocking has been applied

$$t_f = t_{dur} + t_{sw} \tag{6}$$

where t_{dur} is the duration of breaks in shunting movements, shunting from the hump due to failures in devices; t_{sw} is the time from the moment when the switch is disconnected from the electric interlocking till the complete elimination of the failure. If the switch is not disconnected from the electric interlocking, then $t_{sw} = 0$, and if the switch is in manual operation, then t_{sw} is added to the calculation.

Originality and practical value

For visual presentation of dependencies of the daily capacity of a sorting hump and a lead track on the coefficient considering failures in the technical equipment by formula (1) and (6) the calculation with various values of the above-mentioned coefficient has been conducted (Fig. 1, 2). One should pay attention to the fact that increase in the coefficient considering failures in technical devices decreases the values of capacity regardless the value of the established average duration of a hump technological interval which considers the time for entering, pushing, shunting, making-up, backing, as presented in Fig. 1. Obviously, it is connected with the fact that duration of breaks during shunting movements and the shunting of cars from the hump due to failures in devices may add certain time in an operational cycle regarding the breaking-up and making-up operations. The highest value of this coefficient given in [7] is 0,12. While calculating and conducting graphic analysis by formula (1) and (6) in Figures 1 and 2 the increase in the values to 0.2 and 0.3 respectively were used in order to study the problem more thoroughly. The data from [7, 10] of the values of the coefficient considering the failures in technical devices ρ_f for lead tracks are constant parameters: 0.01 and 0.03 respectively, regardless the capacity value.

The experience proves that failures in the signaling and interlocking technical devices occur immediately and their amount at a specific time cannot be predicted, but for a great amount of runs and half-runs on lead tracks and a great number of wag-

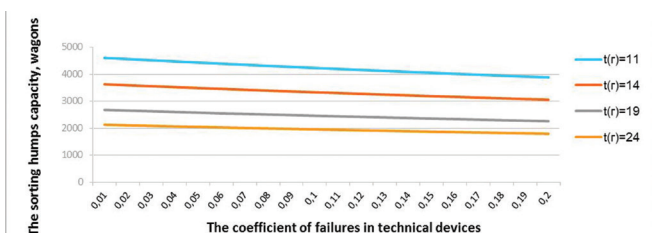


Fig. 1. Dependencies of the sorting hump capacity on the coefficient of failures in technical devices

Tab. 1. Operating cost savings, UAH

	N _t				
	21	22	23	24	25
E _{o.c.} ^I	838,85	878,80	918,75	958,70	998,64
E _{o.c.} ^{II}	699,13	732,43	765,72	799,01	832,31

Źródło: oprac. własne.

ons handled by sorting devises a possibility for failures in the signaling and interlocking devices is increasing. It makes it possible to conclude that the value of the coefficient considering failures in technical devices as shown in Figure 2 is changing.

Use of the constant coefficients ρ_f proposed in [7, 10] gives overestimate values of the lead track capacity. Actual values are from 165 to 180 wagons per day which corresponds to the variation interval of the coefficient of failures in technical devices from 0.15 to 0.25. These values of the coefficient are more grounded as they consider not only failures in braking devices, but also the general state of the permanent way, the value of insulation resistance, sustainable operation of automatic blocking devices.

In order to estimate the influence of failures in technical devices on the traffic operation costs we can use the formula from [6], where savings of operational costs due to demurrage of wagons is defined as follows

$$E_{o.c} = 0,365 \cdot t_h \cdot N_t \cdot m_w \cdot e_w \tag{7}$$

t_h where is the weight-average duration of a hump technological interval, hours;

N_t is the number of trains intended for breaking-out during 24 hours;

m_w is the number of wagons in the train;

e_w is the costs of a freight wagon-hour, UAH.

Calculations of savings of operational costs due to demurrage of wagons are presented in Table 1 in two variants by an example interval of 21–25 trains intended for handling to the sorting station. The first variant shows operational costs for failure-free operation of technical devices, the second variant shows a longer technological interval due to failures in the permanent way condition, insulation resistance, unstable operation of automatic block devices and a higher coefficient which considers the failures in technical devices.

Longer hump technological intervals due to demurrage of wagons lead to lower savings by 17% for 21 trains, and by 16.65% for 25 trains, which can be broken out per 24 hours with the same sorting devices according to annual calculations.

Findings

Study of the problem allows certain forecasting. Increase in the classification yard capacity requires higher reliability of the signaling and interlocking devices, no time wastes during the break-

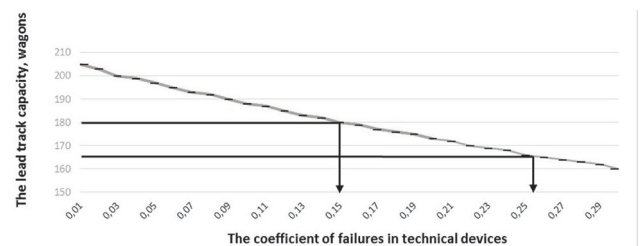


Fig. 2. Dependence of the lead track capacity on the coefficient of failures in technical devices

ing-up and making-up process and better qualitative operational parameters. The ways to improve reliability can be regarded as measures aimed at lower amount of failures and higher repairability. For classification, freight and sectional station operations it has been proposed to maintain the good condition of all elements of the permanent way, among which are the ballast and reinforced concrete sleepers. In order to improve the permanent way the following measures are taken: cleaning and trimming the ballast, cleaning rails and rail fastenings off contaminants, replacing drainage systems at rail sections, if necessary, and overhaul of a track in order to replace life-expired rails. Though these measures improve the track circuit insulation, they do not virtually enhance the operation of automatic block systems under inevitable reduction of carrying capacity of track sections and stations which leads to train delays and longer time wastes, thus decreasing the wagon turnover. The manual cleaning of crushed stone ballast is inefficient and costly. Besides, some contaminants can remain or be added again during the cleaning process. The contamination level of the life-expired ballast material can be reduced more than twice after a usual wash. It can improve characteristics, but high expenses needed for replacement of the ballast, suspension of the traffic during repair and limitation of the speed during stabilization minimize the effect due to repeated contamination. The method can be effective at some sections for a limited time periods. According to schedule from 50,000 to 70,000 m³ the ballast (crashed stone) is replaced every 10 years at the price 70-150 UAH per 1 m³. For a ballast cleaning machine SHCHOM-6U it costs 83,000 UAH, and for a RM-80 it costs 92,000 UAH to clean 1 km of track (at prices for 13 October 2016). Thus, considering high cost for replacing and cleaning the ballast, development of methods to prevent the ballast contamination is of great importance. Under operation the ballast and sleepers are gradually being contaminated [17, 18], and the ballast's ability to drain the water from the permanent way decreases. The ballast and reinforced sleeper contamination with various materials leads to lower electric resistivity of the ballast. It results in forming the 'false occupancy' signals, i.e. indications that an insulated track section is occupied when actually it is free. Decrease in the resistivity leads to a corresponding increase in the stray and leakage current causing corrosion and damage of structures. As early as in the 1960s the railways began intensive replacement of wooden ties for concrete ones, thus providing stable operation of track circuits. Then and now, in order to provide failure-free operation of track circuits at periods of abrupt reduction of ballast resistivity, the method of higher power supply voltage is applied. But the excessive increase can fail the shunt and control modes of track circuits. If the higher power supply voltage does not restore the normal operation of the signaling and interlocking systems, the section is deactivated, which negatively influences train and shunting operation. At Ukrainian railways electric resistance of ballast and ties of track circuits are determined by measuring the ballast resistance, which allows determining the insulation resistivity without deactivating operating devices of the track circuit. Using these measurements it is possible to find sections of track circuits of lower insulation resistance. In order to increase the mentioned resistance there is a need to change electrophysical properties of bulk materials of the ballast layer and concrete by coating them with materials of high electric resistivity [17].

One of the ways proposed to solve the problem can be the coating of the clean ballast before laying it in the track during

repair works and the adding of a component mixture to concrete for sleepers to make their life cycle longer, as well as prevention of adhesion contamination and avoidance of the false occupancy signals for track circuits.

Conclusions

From the above-mentioned one can conclude that failures in the signaling and interlocking devices at stations are not included in the coefficient which considers failures in technical equipment. It helps make a conclusion about possibility to improve the coefficient values which considers the failures in technical equipment by working on parameters influencing it and characteristics of the classification yard capacity, and checking the variability of coefficient values which consider failures in technical devices at shunting operations along lead tracks. Thus, the daily non-stop rail operations while observing the norms for the classification yard capacity and safety regulations during shunting movements are possible by higher reliability of the signaling and interlocking devices through, e.g., higher insulation resistance of track circuits. In practice thin monomolecular water films on the surface of ballast particles contribute to sticking contaminants. Therefore, to decrease the speed of ballast contamination the authors have proposed the method to treat the ballast particles with hydrophobic substances and subsequently add them to the ballast section. Such covering increases the electric resistance of the ballast section and hydrophobic behavior of surfaces of the ballast particles, which leads to lower adhesion of contaminants. To treat the ballast particles, we have used bitumen, silicone and spirit colophony solution [22]. Results of the research have shown that crashed stone treated with colophon covering has the lowest electric conductivity. Its electric conductivity decreased 7.7 times in comparison with untreated crashed stone. Silicone-based coverings have the best hydrophobic effect, this being testified by a limiting wetting angle.

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