

ORIGINAL ARTICLE

DOI: <https://doi.org/10.30932/1992-3252-2022-20-6-6>World of Transport and Transportation, 2022,
Vol. 20, Iss. 6 (103), pp. 174–181

Resource Optimisation of Distributed Manufacturing Processes Using Simulation



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ABSTRACT

Non-destructive testing processes in the technological cycle of a wagon repair enterprise largely determine safety of railway transport facilities. The most effective ways to control such processes can only be determined through simulation which makes it possible to assess stability of the production system in a wide range of both external conditions and internal factors.

The objective of the work is to create a method for optimising the resources of distributed manufacturing processes for non-destructive testing of a wagon repair depot based on simulation to reduce the likelihood of stopping the production cycle and reducing unreasonable costs of the enterprise.

The features of non-destructive testing as a stage of the technological cycle of the enterprise are considered followed by the analysis of information on the qualifications of the specialists of the wagon repair company. The positions of non-destructive testing and controlled details are described and analysed within the framework of the queuing

theory. To optimise the non-destructive testing division, simulation modelling is used, while mathematical statistics methods and correlation analysis are used to process the simulation results.

A built model of a non-destructive testing unit comprises posts at the units for repair of parts of the automatic coupling devices and the wagon bogie, wheel sets. A production personnel management scheme is proposed, which might be a basis for optimising the organisational structure of the non-destructive testing unit.

The simulation resulted in formulating requirements for qualification of non-destructive testing inspectors of the wagon repair depot. It is shown that the optimal strategy for development of a subdivision should be aimed at ensuring the universal qualification of employees, in which they have the necessary competencies to perform work at all testing positions. This will increase the average occupancy rate of NDT inspectors from 0,34 to 0,45 and reduce the average delay time of an item at the post from 650 % to 150 % of the standard time.

Keywords: railway transport, simulation modelling, simulation, production process, non-destructive testing, organisation of production, optimisation, flaw detection.

For citation: Shkolina, D. I., Adadurov, A. S., Bekher, S. A. Resource Optimisation of Distributed Manufacturing Processes Using Simulation. World of Transport and Transportation, 2022, Vol. 20, Iss. 6 (103), pp. 174–181. DOI: <https://doi.org/10.30932/1992-3252-2022-20-6-6>.

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

The intensive path of development of modern production systems requires continuous analysis and optimisation of technological processes by reducing delays between technological operations, minimising non-production costs, and reducing the likelihood of disruption of technological cycles [1; 2]. At the stages of organising production processes and making managerial decisions, quite often there is a need to study and describe the structures of production systems, determine their internal relationships and the influence of external factors [3–5]. Experiments with production processes of existing enterprises are impractical, and often impossible, since in the short term the costs can be many times higher than the planned positive economic effect.

A common way to study processes of all types is simulation modelling, aimed at studying the laws of behaviour of complex technical systems and predicting their development [6–9]. Modelling allows determining the most effective methods of control by testing different effects on

the system in a wide range of both external conditions and internal factors [10–16].

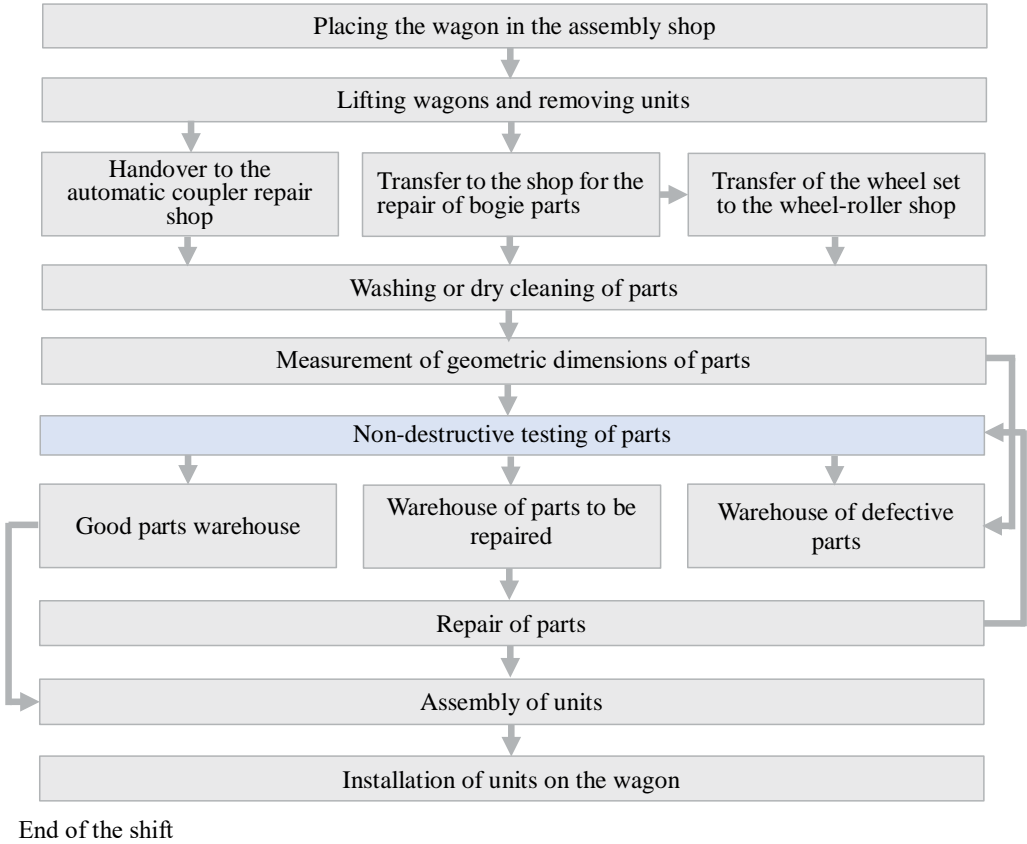
All this is of particular importance for complex processes built into the technological cycle and distributed over different units of an enterprise, the inputs of which are described by random variables. A typical example of such processes is non-destructive testing (hereinafter referred to as NDT), the reliability of the results of which directly affects safety of railway transport facilities.

The *objective* of the study is to develop a method for optimising the resources of distributed production processes of non-destructive testing of a wagon repair depot based on simulation, aimed at reducing the likelihood of stopping the production cycle and reducing non-production costs of the enterprise.

RESULTS

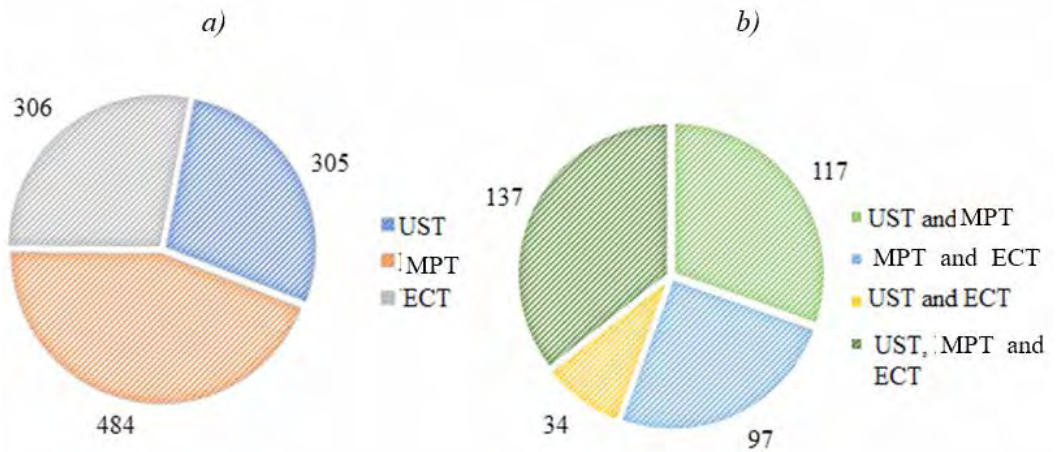
Technological Cycle of the Enterprise

The functioning of rolling stock is based on a preventive maintenance system, which includes maintenance, current, depot and overhaul repairs. In general, the in-depot repair process consists



Pic. 1. Enlarged scheme of the technological cycle of repair of cargo wagons [performed by the authors].





Pic. 2. Distribution of NDT inspectors by certified testing methods [performed by the authors].

of the following stages: placing of a wagon in the wagon assembly area, rolling out the bogie from under the wagon, removal of units and transfer of parts to the repair areas (Pic. 1). The repair of cargo wagons includes NDT, the main purpose of which is timely detection of defects in components and parts, aimed at reducing the risk of failure or accidents of the rolling stock in operation.

The NDT process is implemented in structural subdivisions of enterprises: at production sites, laboratories, workshops, shops. The main difficulty in managing the NDT subdivision is related to distribution of testing positions among subdivisions of the main production: the wheel-roller shop, sections for repair of car bogie parts and of automatic couplers.

Testing is carried out by NDT inspectors certified to apply one or more methods: magnetic particle (hereinafter referred to as MPT), ultrasonic (hereinafter referred to as UST), eddy current (hereinafter referred to as ECT) testing. The main operations, however, are not automated and, therefore, the influence of the human factor on the results of testing is significant. NDT inspectors are assumed to be considered as resources of the NDT production system. In accordance with the current regulatory documentation, NDT inspectors must confirm their competence in authorised qualification organisations by passing the certification procedure for «the Railway transport sector» [17].

Information on qualifications of 834 NDT inspectors from 42 wagon repair depots was analysed (Pic. 2). The largest number of

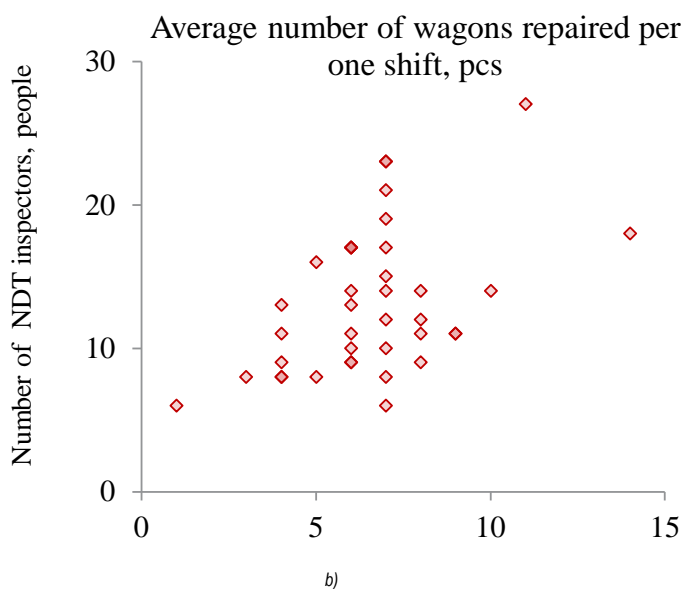
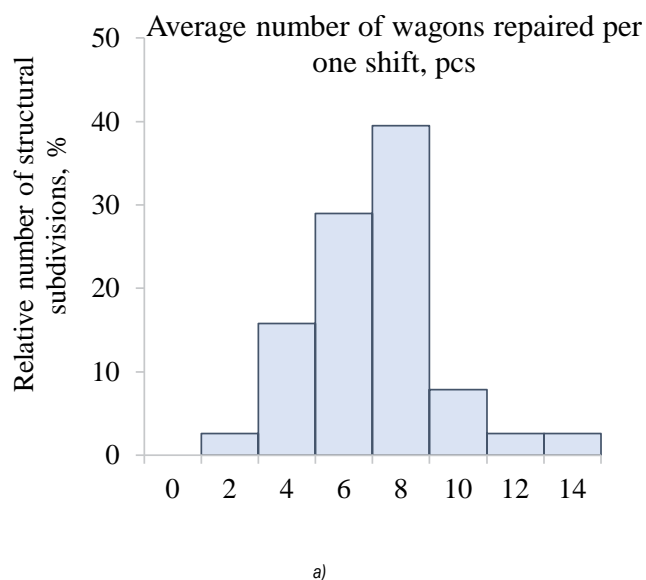
specialists is certified regarding MPT, which correlates with the prevalence of the method in accordance with current regulations. Only 16 % of NDT inspectors are simultaneously certified to use all the three testing methods. Qualification to apply two methods was confirmed by 30 % of defect detector operators (Pic. 2b).

On the one hand, simultaneous certification regarding several testing methods increases the costs of the depot, however, this practice makes it possible to use working time of NDT inspectors more efficiently thanks to their versatility. This approach has been implemented in individual depots, its low prevalence indicates the absence of a single justified strategy for this organisational decision. On the other hand, reliability of control directly depends on qualifications of NDT inspectors, so optimisation of labour resources to perform the daily inspection of cargo wagon parts is a key task, both in terms of economic feasibility and in terms of rolling stock safety.

Simulation

The main problem solved during simulation is to determine an effective strategy for organising control and the optimal number of NDT inspectors required for its performance and their qualifications to unconditionally perform daily volumes of repair of cargo wagons. The necessary information about the daily program for repair of wagons, labour intensity of technological operations, the mode of operation of the enterprise was obtained through monitoring the technological processes of the depot.

The enterprises of the wagon repair company carry out repair of seven wagons per shift on



Pic. 3. Distribution of wagon repair companies (a) and NDT inspectors (b) as per volume of repair operations [performed by the authors].

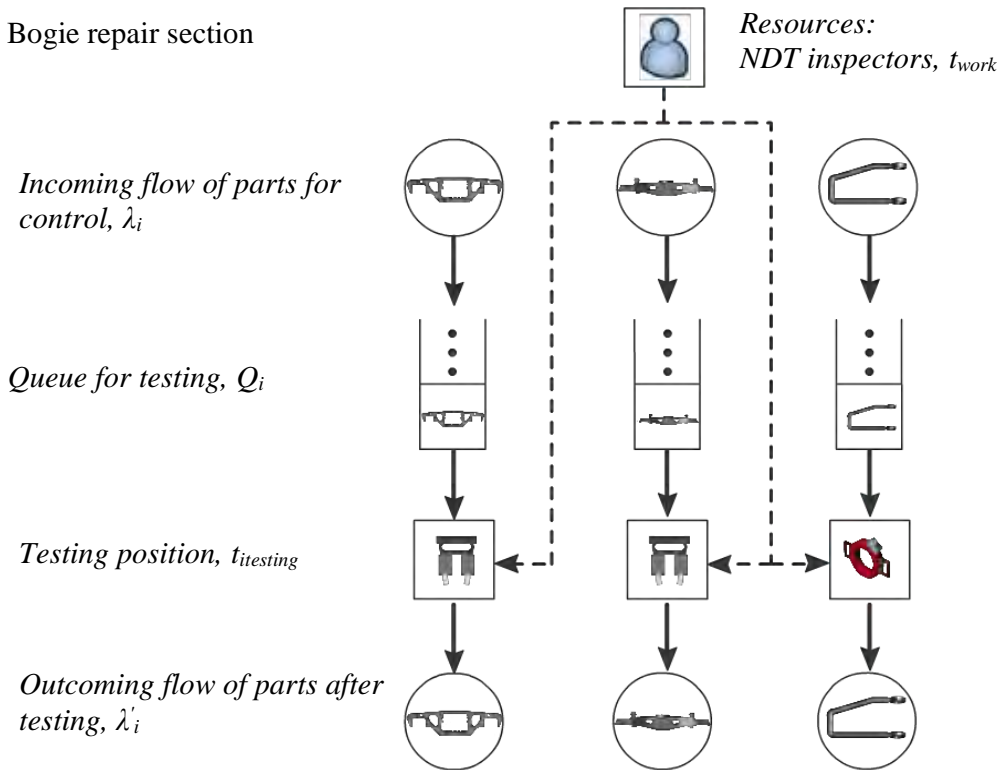
average (Pic. 3a). The number of certified specialists is weakly related to the number of wagons arriving for repair at different depots, the correlation coefficient does not exceed $R < 0,6$ (Pic. 3b). Thus, the structural subdivisions that perform NDT using identical technologies and use standard testing tools do not have a single methodology for determining the optimal number of NDT inspectors.

As part of the study, a simulation model of all testing positions was created at the sites for repair of bogie parts, automatic couplers and

wheel sets of wagons. The initial information was obtained through observation and questioning at wagon repair enterprises and included the hourly number of parts arriving at the testing position during a work shift, the actual number of NDT inspectors per shift, and standard time for testing one part. In the model, the hourly number of parts arriving at the control position was reproduced by a random number generator with a normal distribution law. The average values of the number of parts and their standard deviations required for the random number



Bogie repair section



Pic. 4. Simulation model of testing positions at the site for repair of bogie parts [performed by the authors].

generator were determined based on the initial information.

The production process model contains the incoming flow of parts entering the control, which is characterised by the number of parts and time of arrival. The NDT position is described by the number of parts in the queue Q_i , time of testing of parts of a certain type $t_{testing}$, the equipment used and the number of NDT inspectors certified to apply the testing method. A fragment of the simulation model of the NDT positions at the site for repair of bogie parts (side frame, bolster, brake shoe suspension) is shown in Pic. 4. At the output, a flow of controlled parts with intensity λ'_i is formed. As a result of the model execution, the average delay time of parts at the control positions $t_{testing}$ and the average time of occupancy of the NDT inspector t_{work} are determined.

The adequacy of the developed model was checked by comparing the number of parts tested in the depot with the number of parts obtained as a result of simulation during the period under consideration. The error for each type of parts does not exceed 10 %.

The choice of analysed parameters included the occupancy rate of a specialist during the work shift and the number of parts in the queue for testing (Pic. 5). The productivity of a NDT inspector is characterised by an average occupancy coefficient c_{occ} :

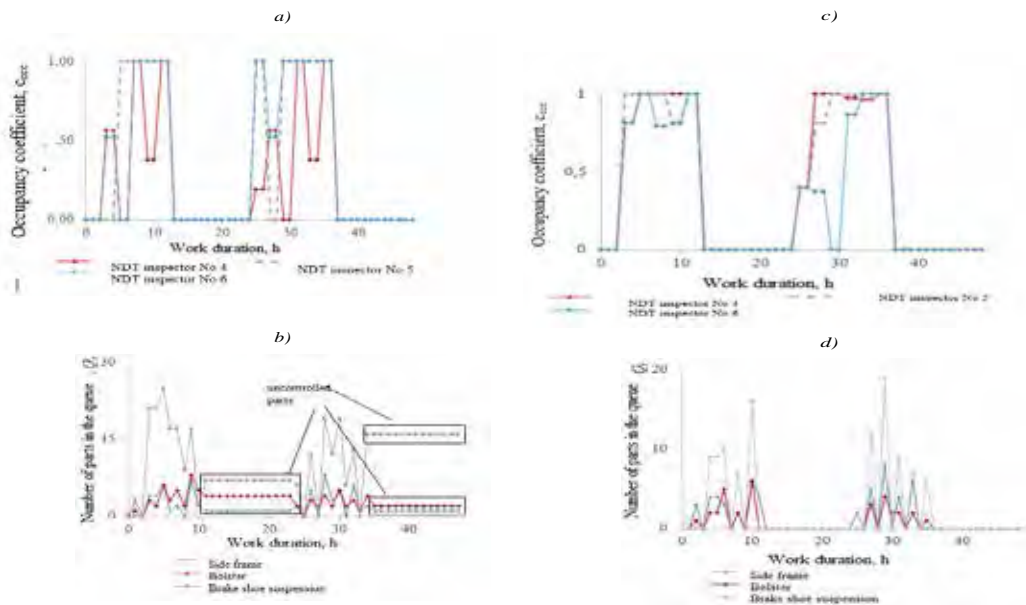
$$c_{occ} = t_{work} / t_{shift}, \quad (1)$$

where t_{work} – average time of occupancy of a NDT inspector, h;

t_{shift} – work shift duration, h.

With given parameters of the incoming flow of parts, the parameters of the NDT technological process are determined by the scheme of placement of NDT inspectors at workplaces. In implementation of the process with assignment of workers to texting positions (Pic. 5a), there is a rather low average per-shift occupancy coefficient $c_{occ} \leq 0,34$, and at the same time, a violation of the enterprise's technological cycle, since at the end of the shift there are untested parts (from 2 to 15 pieces) (Pic. 5b).

The implementation of the process with the universal competencies of NDT inspectors (Pic. 5c), which allows performing work at all

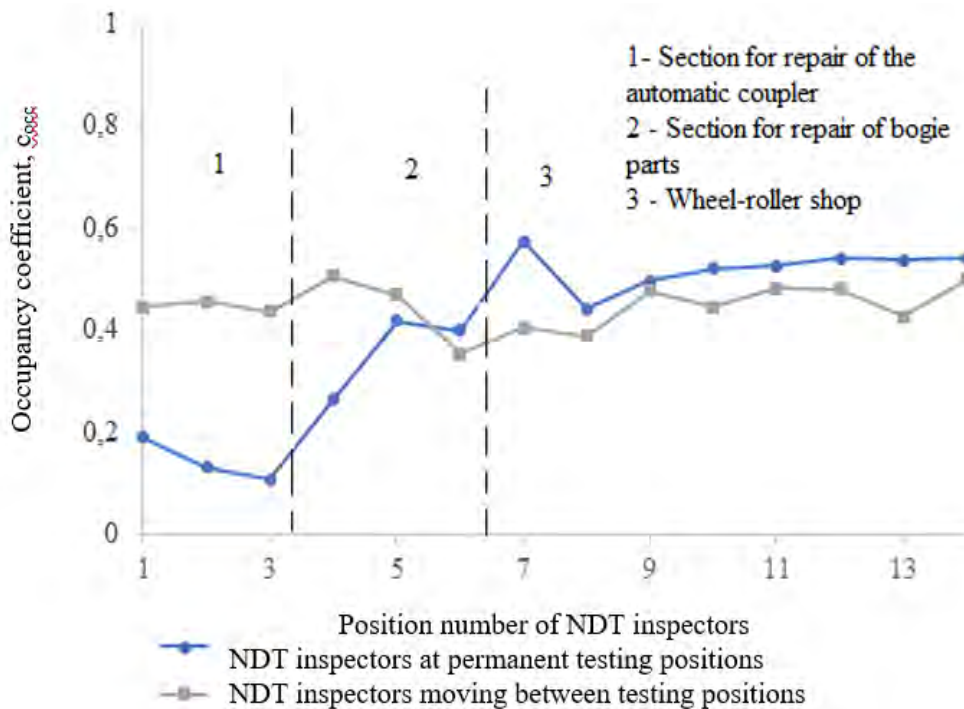


Pic. 5. Occupancy coefficient (a, c) and the number of parts in the queue for control (b, d) during work at the section for repair of bogie parts: a, b – NDT inspectors are assigned to testing positions, c, d – NDT inspectors move between positions [performed by the authors].

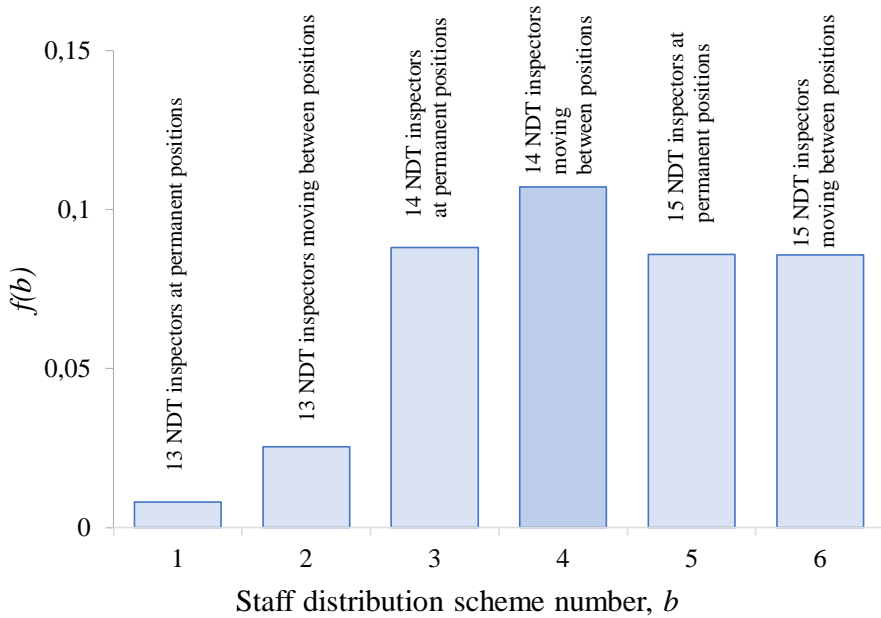
positions, increases the average occupancy rate to $c_{occ} = 0,45$ and prevents the disruption of the technological cycle (Pic. 5d).

The distributions of the occupancy coefficient of NDT inspectors per testing positions in two considered implementations of the process are significantly different (Pic. 6). For example, in

case of consolidation, the maximum workload of workers is observed at the position of the current repair of wheel sets, where the occupancy coefficient reaches $c_{occ} = 0,55$, and the maximum difference in occupancy coefficients at different positions is 0,45. If employees have universal competencies, the occupancy coefficient is



Pic. 6. Average occupancy coefficient of NDT inspectors at different repair sections [performed by the authors].



Pic. 7. Target function graph [performed by the authors].

evenly distributed among NDT inspectors, the maximum difference does not exceed 0,1.

To solve the optimisation problem, the objective function $f(b)$ is introduced, which is equal to the ratio of the occupancy coefficient of specialists to the coefficient of delay of the part at the testing position:

$$f(b) = c_{occ} / c_{part} \rightarrow \max, \quad (2)$$

where b – number on the staff distribution scheme;

c_{part} – coefficient of part delay at the testing position, equal to the ratio of the part delay time at the NDT position to the standard control time.

The selected target function of the labour resources management of the NDT subdivision is aimed at reducing the delay time of parts at the testing position to the standard value and increasing the occupancy coefficient of specialists. The variable parameters of the optimisation problem are the number of NDT inspectors and their competence, which allows or does not allow them to perform work at certain testing positions.

Six schemes of staff distribution (Pic. 7) for a wagon repair depot with a daily repair volume of 6 to 8 wagons are considered. In schemes 1, 3, 5 NDT inspectors occupy permanent testing positions; in schemes 2, 4, 6 NDT inspectors move from position to position if necessary. The number of NDT inspectors in schemes 1 and 2

is 13 persons; in schemes 3 and 4–14 persons; in schemes 5 and 6–15 persons. In schemes 1 and 2, due to the smaller number of employees compared to other schemes, a rather high occupancy coefficient is observed, but at the same time, the daily amount of work is not performed. With an increase in the number of NDT inspectors to 15 in schemes 5 and 6, the entire amount of work is performed, but the occupancy coefficient decreases and, consequently, labour productivity decreases.

The highest values of the objective function correspond to schemes 3 and 4 (Pic. 7). At the same time, in scheme 3 with assigned specialists, the technological cycle is disrupted, since the entire amount of work on the NDT of individual parts (wagon wheel sets) is not performed. The maximum objective function was obtained for scheme 4, in which specialists were able to perform testing at any working position. The free movement of specialists between positions makes it possible to increase the occupancy coefficient from 0,39 to 0,45 and reduce the delay time of a part for inspection from 203 % to 150 % of the standard value, subject to the uninterrupted operation of the wagon repair depot.

CONCLUSIONS

Upon the analysis of production environment of NDT units in wagon repair companies

a simulation model of a complex process distributed over the production areas has been developed that is aimed at optimisation of resources.

Simulation of NDT production process allowed developing of requirements for the qualification of NDT inspectors of wagon repair depot maintaining on average 7 wagons. The simulation has shown that the optimality of a strategy when all the NDT inspectors are certified to apply all the testing methods and have necessary competences, that allows free movement within the NDT unit and execution of all the range of operations. Thanks to optimisation it might be possible to increase the average occupancy coefficient of NDT inspectors from 0,34 to 0,45, and reduce the average delay time of a part at testing position from 650 % to 150 % of the standard time.

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Article received 24.11.2022, approved 27.12.2022, accepted 29.12.2022.

