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The Methodic of Forming a Rational Structure of a Distributed Production Base of Transport Divisions in the Pipeline Industry

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The article deals with the improving the efficiency of transport and technological service of repairing oil pipelines. The subject of the research is the formation of a rational structure of the production base for maintenance and repairing special technics considering technological factors. By using mathematical modeling method relations between technological factors and structure and parameters of production and technical facilities for the maintenance and repairing special machines in the repairing of oil pipelines were obtained.

Key words: Production and technical base, Maintenance and repair of vehicles, Transport and technological machines, Mobile repair workshop, Repair of oil pipelines.

Nowadays, a large number of vehicles is involved in the pipeline industry, which is strategic for the country.

Every year a large number of main oil pipelines (MOP) are repairing. Technological process of repair of the pipeline provides disconnection of the pipeline section or work at reduced pressure for some time. Existing regulations of the pipeline organizations do not allow exceeding standard repair time. Up to 90% of all repairs performed involving vehicles of various categories. Vehicle's failure may increase the length of pipeline repair process operations. In such circumstances, an effective structure of production and technical base for the maintenance and repair transport is required. It should provide a high level of technical readiness, consider regulations and technological factors.

Specificity of production causes the machines to operate separately from the main bases for a long time. Therefore there is a need to maintain and repair vehicles during the repair work of the pipeline. Service can be implemented in one of the elements of the distributed production base (PB): using a mobile repair workshop (MRW) or stationary bases, characterized by different parameters. Vehicle's service process technology must be combined with the process of repair of the pipeline without increasing its timing. Herewith it is not allowed to exceed the rhythm of vehicle maintenance. Currently, there are no algorithms for choosing the element of the production facility for the maintenance and repairing vehicles. Issues of bundling pipeline repair flows funds for maintenance and repair (M and R) of vehicles are not regulated.

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There are a lot of studies on the theory of operation of technical systems[1, 2]. Existing methods of technological calculation of vehicle maintenance units do not include the singularities of Western Siberia oil pipelines' location zone[3]. Also, these methods do not consider the variation of the technology and the volume of work for the repair of pipelines which forms a stream of requests for service and repair of motor vehicles on the elements of the PB.

So, forming the structure of production base for the maintenance and repairing vehicles is the actual scientific and practical task.

Method

Feature of the proposed methodic: primary production (repair of main oil pipelines) is considered as a subsystem. It defines the approaches to the exploitation of vehicles and generates volumes of their works. It affects the amount of work on M and R vehicles and, accordingly, on the values of a distributed production base.

In a system approach, in accordance with the theory of management, the production base has been presented as a system in which has been identified several levels of factors (figure 1).

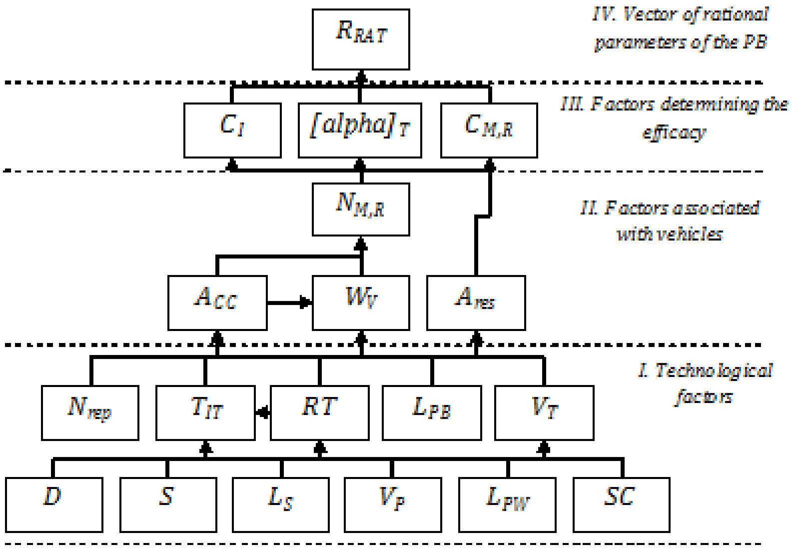

Fig. 1. Interconnection between of distributed production base for M and R vehicles and the main production

At logon are technological factors determining pipeline repair technology (*RT*) and the overall execution time of repairs: pipe diameter (*D*), the length of the defective section (L_s), the thickness of the pipe wall (l_{pw}), the type of soil in the area of repair (*S*), the amount of oil pumped (V_p) and seasonal conditions (*SC*), in which it is necessary to carry out repair work. Technological factors influence on the second factor level: determine the time of vehicles work during the execution of the volume of work to repair MOP (*W*).

Main methods used

A systematic approach, the theory of operations research, the theory of process management, simulation, classification trees, correlation and regression analysis.

Main part

One of the elements of the pipeline transport service industry is production base for the maintenance and repair of vehicles. The production base is buildings, constructions, equipment and accessories for storage, M and R vehicles. Russia has a system of preventive maintenance and repair of vehicles. In it there are several types of maintenance and repair: a daily service (DS), maintenance 1 (M-1), maintenance 2 (M-2), maintenance 3 (M-3 – for special vehicles or tractors), seasonal maintenance (SM), repairs (R).

In the pipeline industry PB for M and R vehicles consists of four elements having different production capacity and the spatial arrangement (table 1).

Each RAOP controls the pipeline section with a few LPDS on it. It has a large number of vehicles of various categories (figure 2).

Table 1. Characteristics of the elements of PB

PB's element designation	Element characteristics	
	Average distance between objects, km	Types of maintenance and repair services at the facility
SP - car service place near pipeline repair area	Over the length of the pipe	DS, M-1, R
LPDS - linear pumping dispatching station	70	DS, M-1, R
CTT - center of technological transport at regional administration of main oil pipelines (RAOP)	300	DS, M-1, M-2, M-3, SM, R
CSS - car service station, usually located in cities	500	M-1, M-2, SM, M-3, R

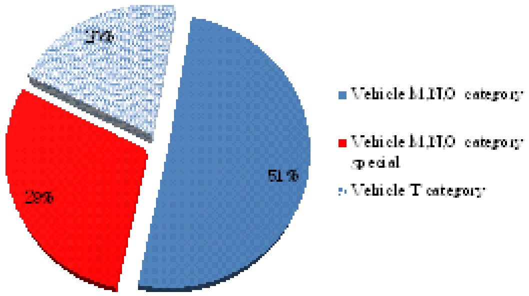

Fig. 2. Vehicle categories percentage in RAOP (according to GOST R 52051-2003)

Analytical studies have shown that in some units there is a significant excess of statutory term of vehicles' repairs. Also, there is excess of the cost of maintenance and repair of vehicles by 20%. This is due to the need of maintenance and repair of vehicles at a distance from the main base. It indicates problems in the functioning of the production base, requiring science-based approach to solving them.

A large number of scientific and methodical works was analyzed. Some works are devoted to improve the efficiency of repair of main oil pipelines[4, 5]. Others aimed at optimizing automobile transport divisions in various sectors of the economy[6]. However, problems of exploitation of vehicles in the repair of main oil pipelines in Western Siberia have not been solved.

Methods used in most of the studies do not permit of exact results under stochastic uncertainty with significant variations of technological factors.

In general, the model for determining the time of vehicles' work during the repair MOP can be written:

$$W_{mn}^{jh} = a_0 + \sum_{b=1}^{q} a_b \cdot x_{ib} \qquad ...(1)$$

where W – work time of n-th vehicle h-th model j-th category in the m-th method of repair pipeline, h; x_b - the main technological factors (pipe diameter, the length of the defective section, etc.); a_0, a_b - the parameters of the regression model.

Average time vehicle operation can be written as (considering the transport division's volume of work needed for repairs of MOP):

$$W_{mn}^{jh} = a_0 + \sum_{b=1}^{q} a_b \cdot x_{ib} \qquad ...(2)$$

where T_E - average time vehicle operation, h; N_{rep} - the number of pipeline repairs, assigned to the transport division, pcs.; A_{cc} - vehicles involved in the repair of pipeline; m - method of repair of the pipeline; H - number of models of this type of vehicle.

According to specifications service and repair of vehicles should be implemented in the time between shifts. Due to the nature of the pipeline repair technology vehicles in the repair of the pipeline do not have time between shifts. Analysis of vehicles' work showed that the operation of vehicles is intermittent (figure 4).

The time intervals during which the vehicle is waiting for the next processing step and temporarily is not involved are called technological idle time (T_{IT}). It can be used for M and R vehicles.

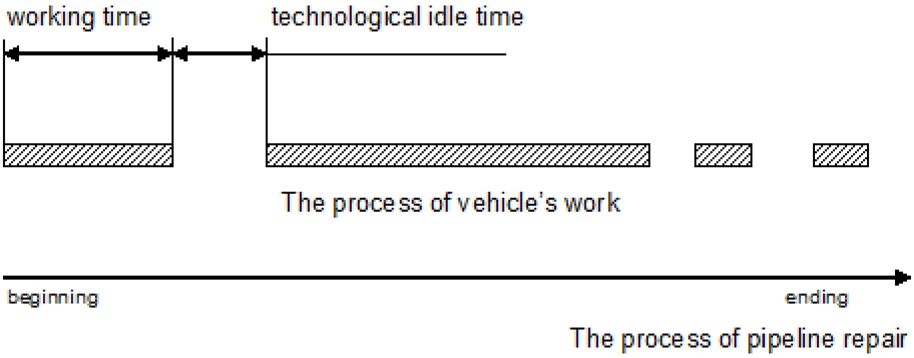

Fig. 4. Diagrammatic representation of working of vehicle at pipeline repair

In general terms, this index can be represented as:

$$T_{IT\,mn}^{\;jh} = (T_{rep\,m} - W_{mn}^{jh}) \cdot k_{mn}^{jh} \quad (3)$$

where T_{rep} - the duration of the repair of pipeline, h; k - empirical coefficient characterizing the discontinuity of technological idle time $k \in [0,1]$.

So, M and R vehicles can be implemented without additional costs with the proviso that the total time of vehicle maintenance or repair will be less than its technological idle time:

$$T_{TI\,i}^{\;hj} \geq \tau_{\eta}^{hj} / N + L_i^{hj} / V_i^{hj} + t_{st} \quad ...(4)$$

where T_{TI} - technological idle time of vehicle j-th category h-th model in the repair of the pipeline, h; T^{hj}_{η} - the average complexity of η-th operation (TS-1, TS-2, TR) in the j-th vehicle h-th model, man-hours; N - the number of workers employed at the M and R vehicles, pers.; L^{hj}_i - the distance from the location of the j-th vehicle h-th model to the i-th element of the PB, km; V^{hj}_i - average speed of j-th vehicle h-th model to the i-th element of the PB, km / h; t_{st} - set-time work during the M and R vehicles, h.

If the total time for maintenance or repair of vehicles exceeds the TIT, it will take additional cost of using the backup vehicle (A_{res}) for compliance work technology. On the other hand, the cost of M and R vehicles on PB's elements will decrease due to decrease complexity of stationary bases unlike platforms in pipeline repair places.

Structural indicators distributed PB (R_{RAT}) were estimated by value of the coefficient of technical readiness of vehicles:

$$\alpha_T = \frac{T_E}{T_E + T_{MR}} = \frac{\sum_{i=1}^{Acc}\sum_{m=1}^{4}\sum_{j=1}^{3}\sum_{h=1}^{H} N_{rep_m} \cdot W_{im}^{jh}}{\sum_{i=1}^{Acc}\sum_{m=1}^{4}\sum_{j=1}^{3}\sum_{h=1}^{H} N_{rep_m} \cdot W_{im}^{jh} + \sum_{i=1}^{Acc}\sum_{m=1}^{4}\sum_{j=1}^{3}\sum_{h=1}^{H} N_{rep_{im}}^{jh} \cdot (t_{MR\,im}^{jh} + t_{id\,im}^{jh} + t_{transp\,im}^{jh} + t_{st\,im}^{jh})} \quad ...(5)$$

where *[alpha]*$_T$ - coefficient of technical readiness of vehicles; $T_{M,R}$ the average time of vehicles maintenance and repair, h; $N_{M,R}$ - the number of M and R vehicles for a period of time, ed.; t_{MR} - runtime normative of one M or R, h; t_{id} - average waiting time of release of the working post, h; t_{transp} - average time of transporting the vehicle to a place of car service, h.

After modeling a rational production structure is taken when the maximum efficiency index was achieved (*[alpha]*$_T$*→max*). Limitations of the model: minimizing the cost of transport support of pipeline industry (the cost of performing the work plan of M and R vehicles (N_{MR}), and the financial loss caused by a deviation from the plan) and performing all volumes of work for M and R cars:

$$\sum C = C_M + C_{M,R} + C_D + C_C + C_B + C_L \rightarrow \min \quad ...(6)$$

$$\overline{|\Delta T_{M,R}|} \rightarrow \min \quad ...(7)$$

$$P(T_{rep}) = const \quad ...(8)$$

where ΣC - the total cost of the maintenance and repair of vehicles, rub.; *[delta]*$T_{M,R}$ - the difference between the required volume of work of M and R vehicles and the possible volume of work for PB's elements, h; $P(T_{rep})$ - the probability of pipeline repair at normative time; C_M - the cost of moving vehicles, rub.; $C_{M,R}$ - the cost to perform M and R, rub.; C_D - depreciation, rub.; C_C - the cost of consumables to perform M and R, rub.; C_B - the cost of using the backup vehicle, rub.; C_L - monetary losses from vehicle's idle in waiting of release of the working post, h;

On the basis of the theory of operations[7] simulation method was chosen. It allows to obtain accurate results in terms of non-Markov stochastic uncertainty processes. Developed simulation algorithm is shown in figure 5.

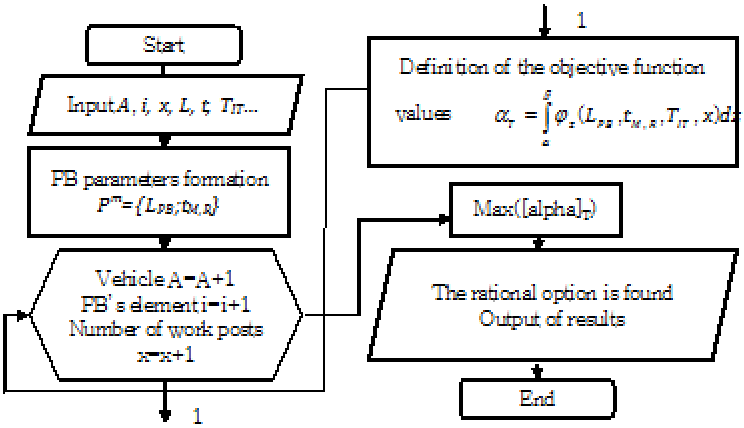

Fig. 5. The algorithm to select a variant of the rational structure of distributed PB for M and R vehicles

At the first stage the matrix of parameters of PTB is forming, taking into account the distribution of random variables: distance between PB's elements (L_{PB}), complexity of M and R (t), vehicles' technological idle time at the pipeline repair, the parameters of each category of vehicles. Further, for each category of vehicles the process of " and R on PB's element is modeling. Simulation is performed for different number of posts of M and R on the PB's element. When a predetermined number of cycles and constraints were obtained the optimum values of PB's parameters are defined. The process is then repeated for the other categories of vehicles. Element that achieves the greatest value of the objective function will be rational for this category of vehicles. And number of posts and MRW, in which the element reaches the minimum costs and performs the specified conditions, will be rational for this element of distributed PB.

The experiment was conducted in two phases - the collection and processing of statistical information about the operation of vehicles in the repair of pipelines and simulation.

To study the effect of factors on the choice of a rational element of the production base for M and R vehicles was used classification trees (decision trees) method (algorithm C & RT) [8] submitted in STATISTICA 6.0 (figure 6).

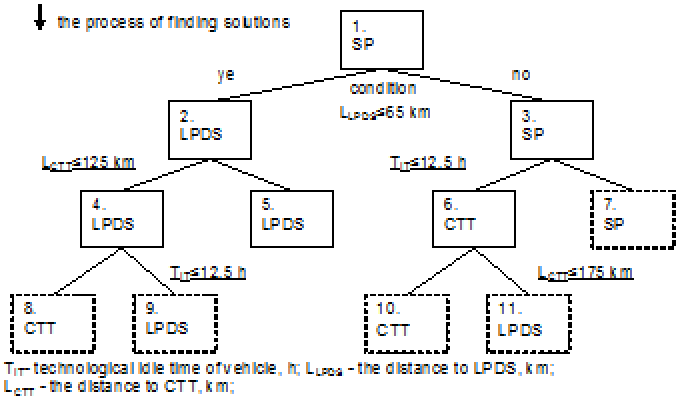

Fig. 6. Decision tree for choosing the rational element of the production base for M-2 vehicles categories M, N, O

For various factors, this method allows us to represent the dependence of the target variable on the independent variables in a hierarchical structure. Each object corresponds to a single node, giving the solution. The left branch indicates to perform a logical expression on one of the influencing factors. Guided by the resulting graph, according to the established criteria of efficiency one can determine the most rational element of production base for M and R of vehicles for different values of influencing factors.

Model patterns of influence factors on the parameters of PB were established as a result of the experiment.

It was found that the amount of MRW, required for vehicle M and R at each pipeline repair method, depends on the diameter of the pipeline and the length of the cut (defective) portion. Models of correlations between the required number of PARM for M and R vehicles, involved in pipeline repair, with technological factors were obtained by regression analysis[9] method. Final regression equations are as follows:

$$X_{MRW}^{PR} = -0{,}77 + 0{,}02 \cdot L_S + 0{,}0012 \cdot D \quad ...(9)$$

$$X_{MRW}^{CI} = -8{,}57 + 0{,}00138 \cdot D + 1{,}269 \cdot \ln(L_{def}) \quad ...(10)$$

$$X_{MRW}^{G,W} = -1{,}07 + 0{,}00067 \cdot D + 0{,}043 \cdot \sqrt{L_{def}} \quad ...(11)$$

where X_{MRW} - the number of MRW for timely implementation of all works of maintenance and repair of vehicles (at pipeline repair by replacement pipe fragment (X^{PR}_{MRW}), coupling installation (X^{CI}_{MRW}), grinding, welding ($X^{G,W}_{MRW}$); D - pipeline diameter, mm; L_S - the length of the cut section of the pipeline, m; L_{def} - length of the defect to be repaired, mm.

Factors that must be considered when developing needs in the posts (MRW) on the elements of the PB were also identified. Models of depending the number of posts on the elements of the PB from technological factors are of the form:

Table 2. Practical recommendations to equip pipeline repair flow by mobile repair workshops

Pipeline repair method	The values of the factors for which there is demand for mobile repair workshops	The distance between the place of ve hicle's work and it's base in which the MRW should be included in a team
Replacement pipe fragment	D≥1220mm, L_S≥15 m	L ≥ 20 km
Coupling installation	D≥1220 mm, L_{def}≥500 mm	L≥ 180 km
Grinding, welding	D≥1220 mm, L_{def}≥60 mm	L ≥ 200 km

Table 3. Coefficients of correction the need of MRW for LPDS (fragment)

Range of variation of the number of pipeline repairs per month	Coefficient of correction the need of MRW for pipeline repair method		
	Replacement pipe fragment k_{RP}	Coupling installation k_{CI}	Grinding, welding $k_{G,W}$
6-10	1,25	0,65	0,95
11-15	1,48	0,77	1
16-20	1,72	0,89	1,07

Table 4 . Recommended allocation of work of M and R vehicles on PB's elements

Vehicle categories	Rational element of production base by types of work			
	M-1	M-2	M-3	R
M,N,O category	LPDS	LPDS	-	CTT
M,N,O category special	SP	LPDS	CTT	CTT
T category	SP	LPDS	LPDS	CTT

$$X_{MRW} = 0{,}065 \cdot N_{rep}^{\;0{,}69} \cdot \left(\frac{L_{PB}}{V_{PB}}\right)^{0{,}57} \quad ...(12)$$

$$X_{LPDS} = 0{,}091 + 0{,}02 N_{rep} - \frac{L_{SP}}{V_{SP}} + 0{,}56 \frac{L_{CTT}}{V_{CTT}} \quad ...(13)$$

$$X_{CTT} = 1.59 + \sum_{i=1}^{z} 0{,}06 \cdot e^{-0.131 \cdot L_{LPDS} / V_{LPDS}} \cdot N_{rep} \quad ...(14)$$

where $X_{MRW,\,LPDS,\,CTT}$ - the number of MRW, posts on LPDS, CTT; L_{PB} - distance from SP to the nearest stationary element of PB km; V_{PB} - technical speed of the vehicle to the nearest stationary element of PB, km / h; N_{rep} - number of repairs on the plan for this section of the pipeline, ed.; L_{SP} - the average distance from SP to LPDS, km; L_{CTT} - distance from LPDS to CTT, km; $V_{SP,\,CTT,\,LPDS}$ - technical speed of the vehicle (trawler) between corresponding elements of PB, km / h; L_{LPDS} - distance between LPDS and CTT on this section of the pipeline, km.; z - number of LPDS from a considered RAOP.

With different ratios of pipeline repair methods coefficients of the obtained models are changing. The adequacy of models is determined by the value of Fisher and the average error of approximation. For all models, $E \le 15\%$, and the inequality $F \le F_{\alpha;\beta;k}$.

The essence of the proposed approach and the process of obtaining the results presented in more detail in the works[10, 11, 12].

Using achieved models the methodic of

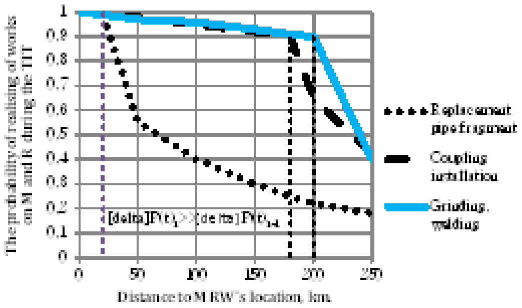

Fig. 7. Change of the probability of timely execution of maintenance and repair of vehicles from the base of MRW

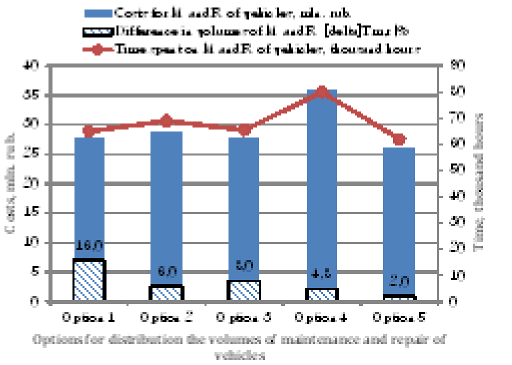

Fig. 8. Comparison of options for distribution the volumes of maintenance and repair of vehicles between elements of PB

determining the rational parameters of the production base for M and R vehicles was developed. This methodic is implemented as software in MS Visual Basic. It may be useful to managers of the operation and maintenance of vehicles in the regional administration of main oil pipelines and its structural divisions.

Conclusions and recommendations

Application of the developed methodic for Tobolsk RAOP allowed to give recommendations to improve the effectiveness of the transport service of the pipeline industry.

It was found that M-1 of vehicles M, N, O, T categories away from the main bases efficiently implement using MRW with rapidly deployable modular buildings.

To ensure continuity of the pipeline repair process when crossing the threshold distance from home base of MRW it should be included in the pipeline repair flow (Figure 7).

On the basis of experimental calculations were formed practical recommendations for determining the need of MRW for M and R vehicles (table 2).

For the convenience of practical use the monthly demand for MRW for LPDS was presented as the norm equal to 1 unit. The norm should be adjusted according to the formula (15), depending on the changing the values of factors:

$$X_{MRW} = X_{MRW}^{norm} \cdot k_{RP} \cdot k_{CI} \cdot k_{G,W} \quad (15)$$

Coefficients are defined as the ratio of the required number of MRW with rejection factors from the norm to the regulatory requirements for MRW for LPDS. The calculated correction coefficients are presented in table 3.

For Tobolsk RAOP it was considered 5 options of distribution the volumes of work of maintenance and repair vehicles between PB's elements. They were compared by 3 criteria: the total time and financial costs of M and R vehicles, the ability of PB's elements to perform the volumes of work of maintenance and repair vehicles, taking into account their available power (Figure 8).

As a result of studies for each category of vehicle there were identified rational elements of PB for works on the M and R. Recommendations: strengthening car service bases on LPDS to 2 posts, to complement them the universal high-performance equipment, to carry out there work of M-1 for vehicles of categories M, N, O and M-2 for all categories of vehicles. CTT, because of their large distance from places of vehicles' employment, recommended to specialize on labor-intensive work of M-3 and repair for all categories of vehicles (table 4).

The economic effect is achieved by reducing the unit cost of M and R vehicles. The rational element of the PB for each category of vehicle is determined by comparing the current option of the allocation of work (option 1 in Figure 8) and the proposed option (option 5 in Figure 8). Using of the proposed method will enhance the value ±T at 6%, reduce the number of reserve units of vehicles, reducing the average downtime of vehicles in M and R at 71 hour per month, reduce unit costs for maintenance and repair of vehicles at 4836 rubles per month and keep the level of reliability of transport services of primary production.

RESULTS

1. A mathematical model of operation of vehicles in the repair of main oil pipelines was developed. This model takes into account the influence of technological factors of pipeline repair. Also, the model allows to make optimization of the existing structure of a distributed production base by maximizing technical readiness factor and performing set limits.
2. The regularities of the influence of technological factors of the pipeline on the selection of an element of production base for M and R vehicles were established. It was found that the economic feasibility of the M and R vehicles at PB's element varies with the technological idle time in repair MN and the distances to the bases. For different categories of vehicles the model of this process is implemented using decision trees method.
3. The regularities of influence of technological factors on the need of mobile repair workshops for maintenance and repair vehicles for each method of selective repair of the pipeline were set. They are described by two-factor additive regression models. Revealed that for Western Siberia need to enable MRW in pipeline repair flow occurs when executing time-consuming repairs of MOP on replacing more than 15 meters of the pipeline diameter of 1220 mm at a distance from the base for more than 20 km. In other cases, it is advisable to use MRW as needed with home base at LPDS.
4. The regularities of the influence of technological factors on the demand for MRW and stationary posts of M and R vehicles when transport division has a fixed annual amount of work on selective repairs of main oil pipelines. They are described by multivariate regression models. Number of posts of M and R vehicles depends on the volume of works on repair of pipelines by various methods, and the largest weight has pipe replacement method.
5. The methodic of forming a rational structure of a distributed production base of transport divisions in the pipeline industry was created. Unlike existing, this methodic takes into account technological factors of pipeline repair. For the convenience of practical use, it is represented as a pilot version of the workstation. It allows engineers to effectively manage the processes of vehicles' maintenance and repairs.
6. There were developed recommendations for Tobolsk regional administration of main oil pipelines to form a rational structure of PB for M and R vehicles. Recommended to

implement M-1 vehicles at a distance from the main bases using MRW, increase the power of bases in LPDS to execute there M-2 for all categories of vehicles. Recommended to specialize CTT bases to perform labor-intensive work of TO-3 and repairs of all categories of vehicles. Estimated economic effect is 4836 rubles per vehicle per month.

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