Architecture of the decision-making system concerned to the management of repair of the motor-vehicle transport at the large-scale enterprise

S Ya Egorov¹, A V Kalach¹², Salih H S³, A V Zatonsky⁴ and M N Felker⁴

¹Tambov State Technical University, Russia, Tambov, Leningradskaya, 1a
²Voronezh institute of the Russian Federal Penitentiary Service, Russia, Voronezh, Irkutskaya 1a
³Ministry of Higher Education and Research of Iraq
⁴Permian National Research Polytechnic University

E-Mail: AVKalach@gmail.com

Abstract. Architecture of the system for support of the decision-making for the transport vehicles enterprise providing the balance between reliability and costs. This allows providing a decision-making person with reliable and qualitative information concerning consequences of the choice between this or that kind of repair. Technical realization of this approach is implemented with the use of 1C-accounting software.

1. Introduction
Support of decision-making is an efficient way for increasing of the quality management as in production as in provision of services including the freight services. The growth of scale in the activity of the vehicle transportation enterprise inevitably results in the proportional and sometimes priority growth rate of complexity in support of decision-making [1]. This support is provided by a wide application of the systems based on Big Data, Data Mining for the reason of the information from the data storage (DS) and the basis of ontology systems. All of them are based on the models of different nature implicit for the user after the layer of the intellectual technologies of the data processing. In this situation both exploratory models (including regression ones) and inexplicable models – ARIMA, neural networks [2], models on the basis of fuzzy mathematics. The use of activities models proves to be efficient if the problems of choice or assessment of consequences of the control actions are so great that they cannot be solved in algorithmic ways for the reasonable time. In these cases [3] the method of embedding the decision-making person (DMP) himself into the control loop seems to be rather efficient. By realizing hardly formulated rules formed within the period of his previous activity a man can discard deliberately unacceptable solution or choose the best solutions basing on the informal approach. The task of the information system in this case is to calculate consequences of the decisions accepted by DMP, and no more.

As it was justified in [4], the problem of decision-making associated with the preventive or operative financing of the repair works becomes critically important for the large-scale vehicle-transport enterprise with a vehicle fleet having nonzero wear.

2. The theoretical part
The problems of the repair or replacement appear when the equipment or vehicles go out of date with time, when they are worn out and require repair or replacement. The main dependence of this process is determined on the basis of ageing curve or decrease of efficiency of its utilization E(t) (figure 1).
Figure 1. Replacement periods for the components and assemblies of DSM.

For the out-of-date equipment a repair can be executed in the certain points of time $t_1, t_2, \ldots, t_n$ that can naturally increase an efficiency of its use up to the values of $E_1, E_2, \ldots, E_n$. As a last resort, in case if the maintainability is impossible a complete replacement of equipment is implemented. Each of the realized repair assumes certain costs of $C_{p1}, C_{p2}, \ldots, C_{pn}$ kind. So, let the price for a new vehicle (or equipment) is equal to $C_{\text{repl}}$. Interval of time $t_{\text{repl}}-t_0$ from the fact of purchasing of the vehicle (or equipment) up to its replacement we denote as $T_{ij}$ (life-cycle period). The problem of repair requires to calculate the number of renewals $C_{p1}, C_{p2}, \ldots, C_{pn}$ and their terms in order to minimize the mean costs for the repair of equipment over all of its life cycle (the problem of repair may assume replacement of the equipment by the new one or updated variant), meaning that

$$\frac{1}{T_{ij}} \left( C_{\text{zam}} + \sum_{i=1}^{M} C_{pt\cdot t_{pt}} \right) \rightarrow \min$$

However, there is such an equipment where a number of the components (details) completely fail. It is assumed that these components cannot be restored. They can be solely replaced (for example, a lamp, protecting device and so on). In such variant the set problem is slightly modified.

In order to identify possible failures it is required to calculate the periods of time for the preventive check which provide minimum of the total costs for execution of the control procedures as well as the estimated expenditures due to the downtime of vehicles (equipment) and decrease of efficiency in the execution of the necessary technological operations.

Inability of the vehicle-transport enterprise to execute the flow of the incoming orders for transportation of goods in a dependence of the vehicle fleet ageing is enhanced ultralinearly.

Qualitatively the trend of the conventionally linear technical availability is shown in figure 2, where $T_{rab}$ – is an interval of the vehicle preparedness, $T_{rem}$ – is a period of the maintenance or repair for a vehicle.
Here designations \( t_1, t_2, t_3 \) correspond to three obvious periods in the vehicles operation:

1) just after inclusion of the vehicle into the operation or after complete overhaul when in the vehicle it is possible to find defects or mistakes of repair;

2) main period of vehicles operation when the damage probability is enhanced or, in other words, technical readiness is reduced;

3) decrease of the technical readiness below certain level when the probability of an immediate damage is higher than the admissible one (it is required that the vehicle should be repaired and it takes some period of time \( T_{rem} \)).

As a result of repairing technical readiness is recovered but, as a rule, this recovery does not get initial value; as a rule, this value is slightly less than

\[
(0)_{i} \leq (0)_{V} < 1.
\]

The common trend for the deterioration of the after-repairing readiness of the vehicles from one repair act to another one can be represented by the curve \( P_v(t) \) (figure 3).

A curve of the ultimate recovery \( P_v(t) \) after repair acts passes through the points of the trends return \( P(t) \) with its own inclination angle

\[
\frac{dP_v(t)}{dt} = \frac{\Delta P_v(V)}{\Delta t_i} 
\]

where \( \Delta t_i = t_i - t_{i-1} \). If the value of \( \Delta P_v(V) \) is constant, then \( P_v(t) \) represents a linear, however, generally this dependence is non-linear. Hence, the readiness time

\[
\Delta t_i = t_{2i} - t_{1i}
\]

depends on the type of repair \( V \), of initial and defined minimum technical readiness: \( \Delta t_i = f(P(t_{i-1}), \Delta P_v(V), P_{\text{min}}) \).

For the unlimited cycle of the repair acts the time \( t_{\text{crit}} \) is coming after the repair act with a number \( i_{\text{max}} \), when an increase of the technical readiness ceases compensation of the repair costs of the same kind of repair (e.g. current repair of the vehicle). In such a situation more complicated and complex repair is possible (e.g., a complete overhaul); in this case technical readiness is recovered to a greater degree (but it does not attain its primary level \( P_{\text{max}} = P(0) \)).
3. Architecture of the decision-making system

As a result, informational model for provision of the technical readiness for the vehicle (figure 4) involves the following relationships:

- function of dependence of the technical readiness on time
  \[ P(t) \in \{ P_1(t), P_2(t), P_3(t) \} \]

- equation for the determination of the recovery coefficient in a dependence on the number and the kind of repair
  \[ \Delta P_i(V) \]

**Figure 4.** Informational scheme for provision of the technical preparedness of vehicles at the large-scale enterprise.
where $V \in \{TO, TP, KP\}$;
- limiting conditions – maintenance resources of the enterprise

$\Delta R_i (V)$.

Financial resources of the enterprise [4], assigning for support of the technical readiness of the vehicles (let us denote them as $C_i (V_i)$) include variable and permanent costs

$$C_i (V_i) = C_{iv} (V_i) + C_{ic} (V_i)$$

and it is important that for any kind of repair $V_i$, implemented in the moment of time $t_{Vi}$, the condition should be executed:

$$C_{ic} (V_i) > 0 \forall i .$$

Then the problem of determination of the technical readiness for a vehicle takes the form:

$$C_i = \sum_{j=1}^{\infty} \sum_{j=1}^{N_j} C_{ij} (V_i) \to \min$$

subject to

$$C_{ij} (i) \leq C_{ij}^{min} \forall k$$

$$C_{ij} (i) \geq 0 \forall k, i$$

$$P_i (t) \geq P_{min} \forall t$$

where $k$ – is a number of resource kind for making of the $i$ -th repair beginning from the first one and finishing by $i_{max}$, and after that the vehicle is out of operation state. As it was shown above, after identification of the model parameters in the mode of statistical information acquisition concerning the activity of the large-scale enterprise solution of this optimization problem is possible with the use of the simulation modeling.

Specifying the common above-named model it is possible to obtain another expression for the same optimization problem

$$C_{\Sigma} (t_{Vi}) = C_0 (t_{Vi}) + C_{pz} (t_{Vi}) \to \min ,$$

where $C_{o(t)}=C_{zh} + C_I + C_{m} + C_{ir} + C_{ac} – are the resources for the unplanned repairs; $C_{pz(t)}=C_{zh} + C_{m} + C_{tr} are resources for the warning replacement of spare parts in order to delay the repair $V_i; $C_T – are the resources for the travelling of the repair base; $C_{zp} – are the resources for spare parts; $C_{m} – are resources for consumables; $C_{tp} – is the cost of repair works for elimination of unscheduled failure; $C_{ac} – damage (or profit deficiency) due to the downtimes of a vehicle in the inactive state. For each of $j$-th listed products the general costs are calculated

$$C_{0j} (t) = \sum_{k=1}^{N_{0j}} C_{0kj} ; C_{pzj} (t) = \sum_{i=1}^{N_{piz}} C_{piz} ,$$

where $N_{0j}$ defines the number of failures of $k$ kind, while $N_{piz}$ defines the number of $i$-th warning replacements for all operation cycle of the vehicle.

Surely. The limiting condition for the costs from below is the requirement of provision of the minimal technical readiness $P_{min[5]}$.

In case if recovery of the technical readiness of vehicles in the process of warning or emergency repairs is insufficient, they fail, as a result, the workload for the remaining vehicles grows up, the time for their wear life is reduced and so on. However, conventional and the most primitive criterion of the activity efficiency always and everywhere proves to be internal expenditures and one always tries to reduce them. Hence, PDM of the vehicular trucking enterprise is permanently forced to solve Pareto-
optimal task of the choice between the investments to the repairs and decrease of the common technical readiness to the transportation [6].

However, a number of the problems connected with the increase of validity for such choice make it difficult a direct application of the multiple known systems providing support in decision-making (PSDM). Therefore, the aim of this work is the development of substantiate SPDM architecture of the transport-vehicle enterprise providing the balance between the reliability and costs.

Let us enumerate the problems of the life cycle in such kind of PSDM system basing on the idea of possibility of indirect identification while assessment of technical readiness for a vehicle basing on the data for multiple single-type vehicles described in [7]. At the same time let us make discussions basing on the typical damage for freight motor transport, for example, the fault in reduction gear of the driving axle. Obviously, in this situation PDM faces least a dilemma – either promptly replace faulty axle by the reserve unit or implement its repair for rather long time that will always result in a less recovery of the technical readiness though being less cost-based one. This solution should be resolved even in the case of the axle presence in reserve. Common situation attendant the occurrence of decision-making case is presented in figure 5.

Criterion of decision-making concerning amount of repair works is naturally presented by the profit of the enterprise

\[ Pr = In - Co - C \]

where \( In \) – is an income of the enterprise, \( Co \) – is a cost of the repair works, \( C \) – is a cost value of transportation for some period of time in future \( T_1 \), inseparably linked with the technical readiness of the vehicle fleet. Therefore, the following program units are minimally required for PSDM:

1) Calculation of the execution probability of all the incoming applications for the transportation over some period of time in future at a certain level of technical readiness of the vehicles fleet.
2) Calculation of profitability \( In \) of the enterprise due to the execution of the requisitions systems.
3) Calculation of the cost of repair works \( Co \), required for attaining of specified level of technical readiness for the vehicles fleet.

![Figure 5. Life-cycle of transportations and denial of transportations.](image-url)
Traffic handling cost which does not include separately considered cost of the repair works and it is obviously a sum of net costs over all of the vehicles fleet:

\[ C = \sum_i C_i \]

where cost \( C_i \) depends on the hour of manpower cost \( C_i = C_{iq} + C_{iq} \).

\( C_{iq} \) determines the price of one hour for a vehicle of \( q \) type just during its operation (r./v.-hr.), \( C_{iq} \) specifies the costs for queuing of a vehicle of \( q \) kind, which are related with machine hour of the use of vehicle at the engineering development site (r./v.-hr.), i.e.

\[ C_{iq} = k_{wr} \left( \frac{1}{F_{eq}} C_g + C_{teq} \right) \]

where \( C_g \) makes annual expenses connected with a complete overhaul (r./year);
\( C_{teq} \) are operational costs for one hour of the vehicle operation (r./v.-hr.);
\( k_{oe} \) - coefficient determining overhead expenses for the utilization of a vehicle;
\( F_{eq} \) specifies the ultimate annual vehicle fund (v.h/year)

\[ C_{eq} = k_{wr} \left( \sum_{a=1}^{a_0} C_{na} + C_c + \sum_{a=1}^{a_0} \sum_{b=1}^{b_0} C_{ta}^{ab} L_{b}^{q} \right) \]

where \( C_{na} \) - are the costs associated with handling operations at the vehicle, as well as the possible works on coupling-decoupling or assembly-disassembly with/from towing vehicle (r.);
\( C_{eq} \) defines the cost of provisioning of the necessary facilities for the stay of a vehicle at the object which is necessary for the efficient and normal work (r.);
\( C_{ta}^{ab} \) defines the cost of travelling of the vehicle on the transport means of \( a=1\ldots a_0 \) type per 1 km along the roads with the indexes \( b=1\ldots b_0 \) (r./km/km);
\( L_{b}^{q} \) specifies the length of transportation route with the index \( b \) (km).

Overhead expenses associated with the downtime of vehicle are calculated as \( C_{hdtq} = C_{dnq} + C_{eq} \), where \( C_{dnq} \) represent the costs per an hour of the vehicle with a form-factor \( q \), (r./v.-h) and they are equal to \( C_{dnq} = k_{np} \left( C_c \cdot \frac{1}{\rho_g} + 0,5 \cdot (C_{an} + C_{cm_o}) + P \right) \)

where \( C_{dnq} \) represent the cost for the fuel during one machine hour of the vehicle operation (r./v.-h);
\( C_{lab enqu} \) is a factor of expenses for cleaning cloths and lubricants related to a machine hour of the vehicle operation (r./v.-hr.);
\( P_q \) - is a wages of a driver for 1 hour of work (зарплата машинистов за час работы (r./hr.).

As a result, expenses determined in such a way for the realization of the mechanized operations (this is just a measure of efficiency) prove to be an additive function of three arguments

\[ C = C_b + C_q + C_{eq} \to \min \]

where \( C_b \) determine expenses for the operations, vehicle travelling and downtime due to underutilization.

4. Conclusions

Besides some certain features in the calculation of the net cost for motor transport enterprise as compared, for example, with the industrial one the first one is rather highly subjected to the effect of seasonality. Therefore, coefficients for the models calculated according to [7] for the summer time may be different from those ones obtained for the period of slush roads. Hence, firstly, it is required to adopt the models in accordance with the season of a year, and, second, periodically update their coefficients. This can be done by incorporation of the module of internal assessment for the models quality into
PSDM that makes it possible to compare their predictive estimates with the newly incoming data. Attaining of the specified misalignment may be a reason to perform an iterative identification of the coefficients basing on the data obtained for some period of time in the past $T_2$.

Note that the global settings $T_1$ and $T_2$ themselves are not somehow predetermined ones and they must be chosen in such a way that the quality of decision making support would be maximum one. For example, too low value of $T_1$ results in the fact that the effect of a single certain expensive repair can become inadmissibly large while too large value of $T_1$ results in imposition of different seasonal situations requiring different approaches to the repair provision [8].

A separate task is the account and response to the deviations from the planned values of the activity indexes system [9]. On the one hand, these deviations can imply the imperfection of the planning system and PSDM as a whole, when at least the alignment of the inner parameters of PSDM is required. On the other hand, an obvious stochastic character of activity of the vehicle transportation enterprise excludes the absence of these deviations [10].

The general architecture of DSDM is presented in figure 6.

![Figure 6. Architecture of the system for support in decision-making.](image)

Technical implementation of PSDM depends on the software package to be in the disposal of the enterprise including IS of management and account of its activity. 1C-configurations of this package solving these problems are widely spread in Russian Federation (RF). In particular, a list of the vehicles required for this PSMD can be realized in the form of reference book for the fixed assets of 1-C accounting package (figure 7).

In this case some part of PSDM modules can be efficiently implemented in the form of external processes [11], thus making it possible to decrease the risks of failures in the operation of the main configuration. Since the development of this PSMD will naturally occur without suspension of the enterprise activity, as well as without suspension of the operation of the main 1C-configurations providing this activity only the use of external processing let the system to add new capabilities without saving each time configuration of the modules as a whole.
The developed architecture of PSDM allows providing of DMP with valid and qualitative information on the consequences of the choice of one or another kind of repair for the economic efficiency of the transportation enterprise as a whole.

References
[1] Mnif S, Elkosantini S, Darmoul S and Ben Said L 2016 An immune memory and negative selection based decision support system to monitor and control public bus transportation systems IFAC-PapersOnLine 49 pp 143-8
[2] Volodina Yu, Zatonsky A, Rakhimova O and Seredkina O 2017 Predictive model of the flocculation process based on a neural network Bulletin of the South Ural State University 17(2) pp 42-50
[3] Zatonsky A, Varlamova Since 2017 Information support for decision-making on the example of scheduling classes of an educational organization Bulletin of the South Ural State University 18(3) pp 88-106
[4] Egorov S, Salikh X, Zatonsky A 2020 Simulation model of technical readiness of a large vehicle fleet Bulletin of the South Ural State University 2 pp 14-5
[5] Salih H 2020 Methods, models and algorithms for decision support for managing a motor transport enterprise with a distributed structure of serviced objects Tambov State Technical University
[6] Sprenger R, Mönch L 2014 A decision support system for cooperative transportation planning: Design, implementation, and performance assessment Expert Systems with Applications 41 pp 5125 – 5138
[7] Salikh H, Egorov S, Zatonsky A and Plekhov P 2020 Identification of technical readiness of transport and technological machines of a large motor transport enterprise Modeling, Optimization and Information Technologies 8(1)
[8] Abdi A, Taghipour S 2019 Sustainable asset management: A repair-replacement decision model considering environmental impacts, maintenance quality, and risk Computers & Industrial Engineering 136 pp 117-134
[9] Ostroukh A, Surkova N, Vorobyova A and Salih H 2015 Mathematical model of the system of remote diagnostics of automobile malfunctions in the World of Scientific Discoveries 6(66) pp 63-70
[10] Prytz R, Nowaczyk S, Rögnvaldsson S and Byttner S 2015 Predicting the need for vehicle compressor repairs using maintenance records and logged vehicle data Engineering Applications of Artificial Intelligence 41 pp 139-150
[11] Anisimova 2016 Economics, planning and analysis of motor transport enterprises Transport 250 pp