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REPAIR COSTS MANAGEMENT BASED ON MODELS OF UNITS RELIABILITY IN TRANSPORT AND TECHNOLOGICAL MACHINES

ZARZĄDZANIE KOSZTAMI NAPRAWY NA PODSTAWIE MODELI NIEZAWODNOŚCI URZĄDZEŃ TRANSPORTOWYCH I MASZYN TECHNICZNYCH

A b s t r a c t

The approach proposed allows using a more balanced, rational and economically efficient method to the procedures of maintenance and capital repair of transport and technological machinescreating reliability models. To create such models one uses mathematical tools allowing to process obtained experimental data as geometric parameters of aggregates or units and on their basis make up approximating functionsof the parts surfaces wear out during the unit operating time.The patterns of the parts wear out surfaces and the available information on the extreme wear out values serve as the limiting criterion for the onset of a condition in which the failure of parts or the whole unit occurs. For the characteristics of aggregates reliability simulation modeling techniques are involved thatallow the model to obtain the approximating functions for each of the wear out surface of the entire set of components included in the structure of the unit.The information obtained is appliedto the entire fleet of automobiles of the same type; this information provides the basis for determining the quantitative reliability and durability of the test unit. This approach dealing with reliability assessment involves making up a hierarchical model of the structural and functional parameters, which allows you to more fully analyze the failures of the unit and rank them in accordance with the criterion of reliability. Using the model suggested we can estimate both the full and residual life of the unit, determine its basic reliabilityparameters; themodel also allows to take into account the restoration of the units constituent elements involved in repair.

Keywords: *reliability, unit, repair, parts wear out, model*

S t r e s z c z e n i e

Proponowana metoda pozwala na zastosowanie lepiej wyważonych, racjonalnych i efektywnych ekonomicznie metod w procedurach eksploatacji i generalnych remontów w branży transportowo-maszynowej przez tworzenie modeli niezawodności. Do tworzenia takich modeli stosuje się narzędzia matematyczne umożliwiające przetwarzanie danych doświadczalnych w parametry geometryczne agregatów i urządzeń oraz tworzenie na tej podstawie aproksymatycznych funkcji zużycia powierzchni poszczególnych części podczas pracy. Wzory powierzchni zużycia części i dostępne informacje na temat ekstremalnych wartości zużycia służą jako kryterium graniczne dla początku warunków, w jakich następuje uszkodzenie części lub całego urządzenia. Do symulacji charakterystyk niezawodności agregatów zastosowano takie metody modelowania, które pozwalają na uzyskanie w modelu aproksymatywnych funkcji dla każdej powierzchni zużycia całości lub poszczególnych elementów urządzenia. Otrzymane informacje mają zastosowanie do floty samochodów tego samego typu. Informacje te dają podstawę do jakościowego określenia niezawodności i trwałości badanego urządzenia. Metoda związana z oceną niezawodności wymaga stworzenia modelu hierarchicznego parametrów strukturalnych i funkcjonalnych, co umożliwia pełna analizę uszkodzeń urządzenia i jego ocenę według kryterium niezawodności. Przy zastosowaniu proponowanego modelu można ocenić zarówno pełną, jak i uwzględnienie regeneracji elementów naprawianego urządzenia.

Słowa kluczowe: niezawodność, naprawa, zużycie części, model

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Low reliability of local transport and technological machines (TTM) makes the transport companiespurchase new automobiles, a large quantity of spare parts, spend significant amount of money eliminating sudden failures, as well as bear significant losses of idle equipment. All this affects the cost of transport services and, consequently, makes unfavorable changes in pricing policy of service and transport companies, and as a result can not compete with the developed countries of Western Europe.

As the long-standing practice of the leading transport companies showsit is possible to reduce repair expensessignificantly only if we achieve a better quality ofrepair and, consequently, increase automobiles reliability implementing planned maintenance and repair. This approach to repair enables the companies to save considerably on the material (spare parts) and labor force, which frees up cash capital to improve efficiency of their work. Thus, the main objective in improving the quality of repair is primarily to assess the reliability of automobiles, their components and units.

Of great interest is the study ofsuch transmission part as a five-speed manual gearbox of Russian cars “Gazelle”, “Volga” and their modifications, since they are malty-purposes vehicles having wide range of conditions and operating modes, which leads to high loads on the transmission components, including gearboxes.

The list of functions performed by a gearbox requires its high degree of reliability; however, it typically includesfrom ten to some hundred parts or elements, which determineaggregate or unitreliability. Judging by the development of new technologies, reliability of aggregate components has beenimproved, but the improvementrate of aggregate complexity itselflags behind.Thus, the newly developed transmission units, as well as in service units are to meet increasingly high quality requirements;thisin turn requires appropriate methods of calculation, assessment and prediction of their reliability.

A number of scientific papers are dedicated to the issues of assessment of the vehicles reliability. First of all one shouldpoint out the conventional methods of assessing the level of reliability [1], based on the determination of an acceptable level of probability of failure--free operation. Using these methods we usually carry out passive experiments to monitor the controlled sample of studied elements of the whole system in order to fix the failures and to obtain reliability characteristics. However, the methods of this type have several drawbacks. One of the key drawbacks is the inability to estimate the parameters of reliability, if you do not know the statistics on failures of elements, for example, during the commissioning of new vehicle models. The second drawback may include inability to use such methods for parallel commissioningtests, which in most cases reduces the methods reliability.In addition, the methods of this type do not take into consideration the use of automobile parts residual life.

There exists a procedure of estimating the level of reliability [2], based on the application of restoration theory. The latter allows to take into account the limiting value of structural parameter of the car and the characteristic feature ofits change, as well as economic factors, but does not assess the efficiency of the vehicle or its component parts using the current diagnostic parameter.

Quite perspective trend of the reliability level evaluation of the automobile units is to develop approaches based on an analysis of the dimensional characteristics of the parts and their mutual links using creation, analysis and calculation of the size chains [3].

The existingmethod has been based on the above mentioned reliability level of research diagnostic parameter evaluation which takes into account the pattern of the technical condition parameter and its possible value [4]. Using this method one can estimate both the full and residual life of aggregatesbeing diagnosed, but the latter does not take into account the restoration of vehicles working ability or their components. Besides, the development of this method allows to analyze (in most cases) only one link of parts, without considering the whole set of interrelated or interacting elements of the unit and this can negatively affect the accuracy of above mentioned methods.

Many scientific papers of SFU (KSTU) researchers contributing to the appearance of alternative ways of estimating the reliability both of automobiles and their units are based on providing accuracy of contact parts of the dimensional chains [5, 6].

Of greatest interest is the work of [6] in which the quality of the repair is estimated by the residual life of the contact links of dimensional chains. This approach allows determining the reliability of the unit as a wholemost accurately; moreover, it reveals the structural elements of dimensional links, limiting the reliability of the unit. However, determining the residual life of the car, the authors neglected the identification of patterns of the parts surfaces wear out, considering the linear characteristics. The purpose of this work was not connected with the analysis of refurbished units' reliability, but only confirmed the adequacy of the proposed research hypotheses.

Having presentedyou the shortcomings of the existing and alternative methods we would like to suggest a new approach of the automobile units' reliability assessment. This approach can consist of four main stages.

The first stage is characterized by the creation of a hierarchical structural model, which gives an objective and complete information about the number of elements in the unit and their visual interaction. This stage also includes the procedure of wearing out dimensional model creation, which is an integration of interacting and interdependent elements of the size chains (Fig. 1).

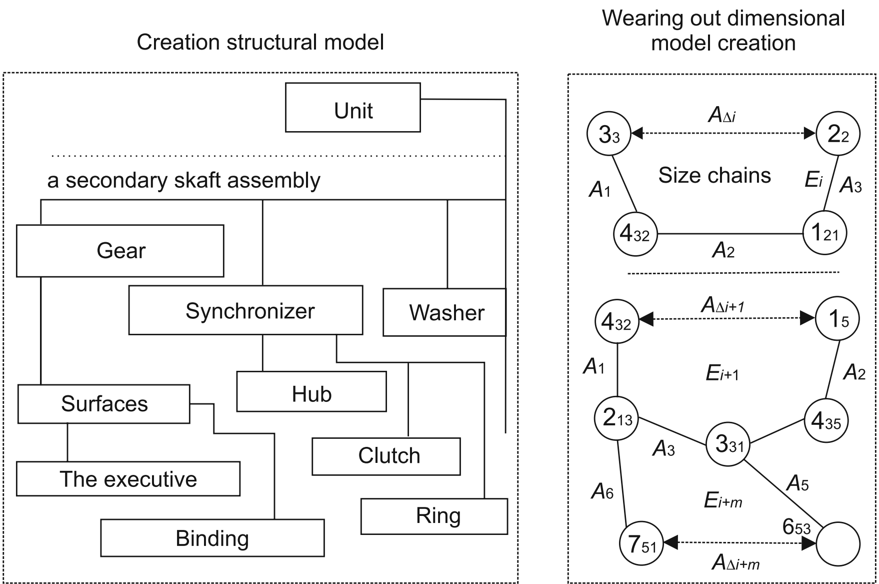

Fig. 1. Structural and wearing out dimensional models

Rys. 1. Modele strukturalne i modele wymiarowe zużycia

The stage of this procedure allows to estimate operating time prior to the elements dimensional links failure or residual life, taking into account the influence of adjacent structure elements.

From a number of studies concerning the parts of wear out surfaces having various functional purposes [4, 7, 8], it is known that the process of wear out surfaces dynamically loaded adjacent car parts even at steady-state operating conditions is nonlinear, but in most cases is close to exponential dependence. That is the process of wear out is characterized by the function:

$$Y = a \cdot e^{bL} \tag{1}$$

where:

- e – basis of natural algorithms,
- L – operating time,
- a, b – coefficients of the regression function, defining the nature and degree of changes in size.

The second stage of the proposed approach deals with obtaining such an approximating function of the parts surfaces wear out as a result of the unit operating time (Fig. 2).

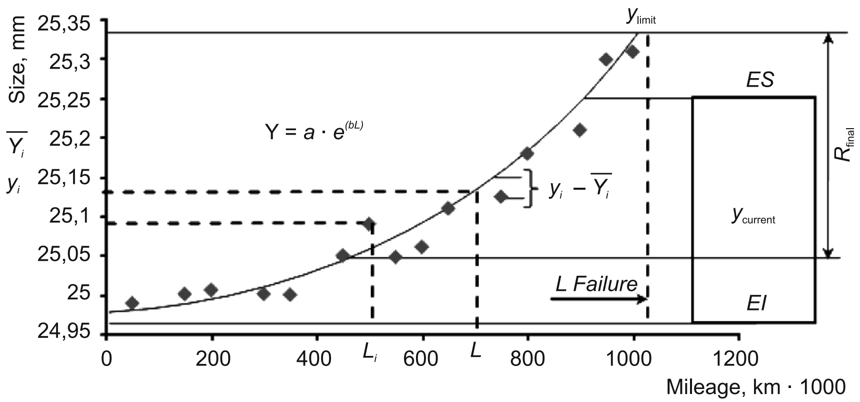

Fig. 2. Approximating function of the parts surfaces wear out

Rys. 2. Aproksymatywne funkcje zużycia powierzchni części

To get approximating function of the unit operating time one uses the least squares method, the essence of which is to find the coefficients a and b depending on z $Y = ae^{bx}$, which describes the experimental data best of all. This condition implies the minimum sum of squared deviations of calculated values from experimental data:

$$Y = \sum_{i=1}^{n} \left(y_i \left(ae^{bL_i} \right) \right)^2 \rightarrow \min \tag{2}$$

Highly relevant and weighty problem is that the susceptibility of emerging approaches to assess the reliability of the processes of recovery of parts or units of vehicles. Dependence of automobile parts surfaces wear out (1) subject to the requirements may be written as follows:

$$Y = ae^{bL} \pm \Delta S \quad (3)$$

where $\pm \Delta S$ – excess or decrease of the actual size within its tolerance with respect to the expectation of the investigated geometrical parameter restored or new parts.

Thus, accumulating statistics of geometric parameters of aggregate parts during its life cycle and knowing the limits of these characteristics one can identify approximating dependence of the parts surfaces wear out or dimensional chain link, besides the curve equation is determined and an array of empirically derived coefficients a and *b* is defined for the purpose offurther modeling.

The integration of geometric dimensions, placed in a closed circuit, which determine adjacent position of one or more components surfaces can be represented as a system of dimensional chains *Ei*, formed at the stage of creating a dimensional model of the studied unit.

When aggregate parts working ability is violated we may calculate the difference between the initial value y_i and $A\Delta$ dimensional chain *E*1 (Fig. 1) and y asextreme values (Fig. 2) one may observe the failure when one of the size chain constituent links (*A*1; *A*2; *A*3) reaches its maximum value (Fig. 1).

To manageautomobile units repair costs it is necessary to obtain basic quantitative indicators of reliability and durability. To have the above mentioned information one must obtain functional dependence (3) of the surfaces wear out process of all the details included in the hierarchical structure of the system connected with the entire fleet of cars, that is for the total amount of objects under control. However, obtaining such data to identify patterns in the natural experiment on the existing transportation facilities is not possible due to cultural aspects and specificity of their work, which does not allow you to disassemble the unit in such a way as to be able to measure the geometric parameters of all the details in the structure of the unit. One possible solution to this problem is the use of simulation techniques, in which the system under study is replaced by a model describing the real system. System in this case includes the patterns of the parts surfaces wear out, and the initial data for the modeling process will be random values a and b of equation (3). This task is carried out in the third stage.

Suppose we have a number *N* of controlled systems (units) *Qi*, where i − the serial or identification number of the unit at the enterprise (Fig. 3).

Each system *Qi* has structural elements *Mi* (parts), and functional elements *Z*i (surfaces). These elements, taken together, form a dimensional model of the studied unit, where the distance between the surfaces of parts and dimensional parameters i – thare considered as links of dimensional chains. Having a random sample $x_m = (x_1, ..., x_m)$ rom the whole integration $\{x\}$ of independent, identically distributed random coefficients values a and *b*, obtained during experimental studies described above, the values of these coefficients can be modeled by mathematical methods.It should be noted that groups of these factors are inherent in a specific structural and functional parameters, i.e. they are connected with functional parameters wear out surfaces *Zi*, (Fig. 3). Completing the modeling process we obtain massive data amount using the known coefficients values, as well as the current value of the geometrical parameter ΔS (the links of size chains) inherent to all aggregate parts, (Fig. 3 (a)). Having executed this procedure *N* times, one gets anintegration of functional dependencies, which give a complete description of all systems under control using wearing out criteria zi, functional elements *Z*i taking into consideration units operating time value L_i (Fig. 3).

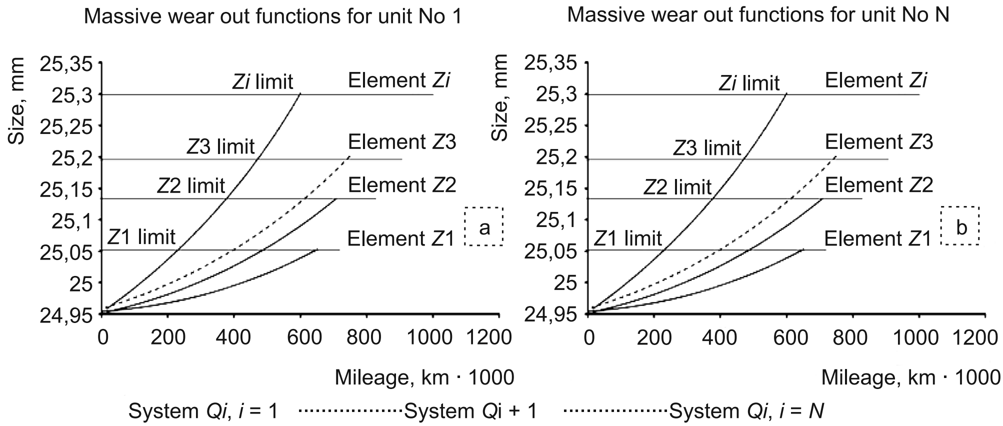

Fig. 3. Massive of modeled wear out functions

Rys. 3. Zamodelowane funkcje zużycia

The fourth stage is evaluation of reliability properties rates in the investigated system. This process can be divided into two main sub stages. The first sub stage is characterized by obtaining point estimates of reliability characteristics (Fig. 4).

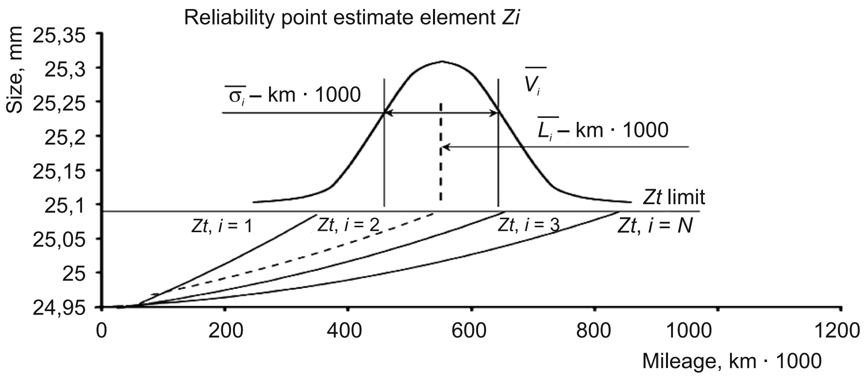

Fig. 4. Diagram of reliability point estimates

Rys. 4. Wykres ocen niezawodności

To get these parameters all curves integration of wear out *Zi* is grouped according to their functional characteristics and one makes up a beam of curves describing the random process of geometric parameters changes during units operating time. When we know the limiting value of the functional element geometrical parameter we can determine point estimates: failures variables – $\overline{V}_i$, mean square deviation – $\overline{\sigma}_i$, mean operating time before failure – L_i.

Mean operating time before failure is the mathematical expectation of the unit or its part prior to the first failure, while at the same time, any element of the unit operating time is a discrete uniformly distributed random value, that is why mean operating time prior to failure is determined by the formula:

$$M[L] = \frac{1}{n}\sum_{i=1}^{n} L_i \tag{4}$$

where:

n − the number of aggregate structural elements,

L_i – operating time prior to failure in the aggregate structural elements of TTM.

For qualitative assessment of automobiles aggregates reliability level it is necessary to know not only the main parameters of the system reliability as a whole, but also be able to get, evaluate and analyze the same characteristics of the aggregate structural elements. For this purpose functional elements massive is sorted in groups according to the increase of their mean operating time at which the functional element of geometrical parameters reaches its maximum value (Fig. 5).

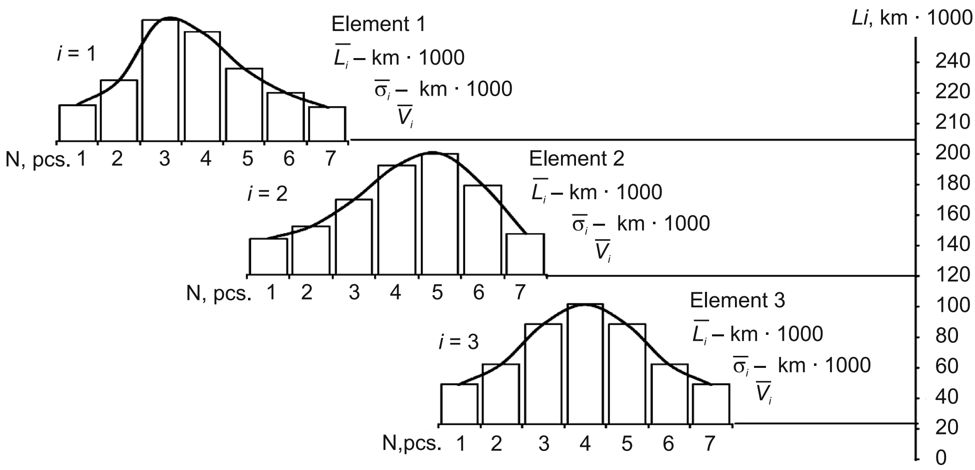

Fig. 5. Grouping of elements according to their mean operating time

Rys. 5. Elementy pogrupowane według ich średniego czasu działania

This will allow disclosing structural and functional parameters of the whole system reliability.

The second stage of reliability assessment is characterized by obtaining the system reliability parameters (Fig. 6).

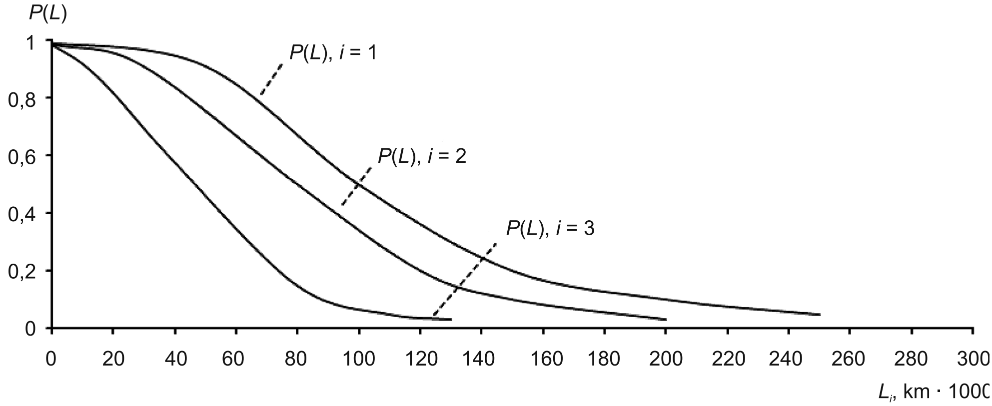

Fig. 6. Evaluation of a system non failure operation rates

Rys. 6. Ocena bezawaryjnego działania systemu

Reliability, tend to be probabilistic in nature, the most common of these are indicators such as the probability of failure-free operation and the mean time to failure.

For these indicators point to the known values of the characteristics of reliability evaluation of structural elements made of reliability of the system. Probability of each structural elements failure is determined according to the formula:

$$P_i = n_i/N \tag{5}$$

where:

n_i – the number of structural elements failure during modeling,

N – the number of auto structural elements in operating conditions taken for control.

The proposed approach TTM aggregates reliability level based on modeling of dimensional chains operating time prior to failure has substantial advantages in comparison with statistical evaluating methods:

– Application of the above discussed method provides models working ability to evaluate reliability carrying out parallel operating tests which increase their "susceptibility" and accuracy;
– Use this method allows to estimate both full and residual life of aggregates being diagnosed and also allows taking into account extreme values of auto aggregates functional elements geometrical parameters.

Besides such approach has great practical importance:

– Allows to predict expenses for auto aggregates repair and plan technological process of repair;
– The suggested method allows putting reasonable requirements to auto design and production technology of units;
– Gives new prerequisites to develop resource consuming repair technologies.

The advantages listed and practical value of the described method offers new opportunities for further development of automated means to evaluate auto aggregates reliability level taking into consideration cars functional elements geometrical parameters. Applying the proposed approach at production site one may estimate auto aggregates reliability level according to common principles in the theory of reliability on the stages of commissioning, trial operation, and besidesto simulate aggregate parameters and obtain its reliability characteristics.

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