**N E W S**
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
**SERIES OF GEOLOGY AND TECHNICAL SCIENCES**
ISSN 2224-5278
Volume 2, Number 440 (2020), 96 – 102 **https://doi.org/10.32014/2020.2518-170X.36**

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# QUALITY ASSESSMENT OF MULTI-PARAMETER CONTROL OF VEHICLE COMPLEX SYSTEMS EFFICIENCY

**Abstract.** The aim of the study is to quantify and predict the risks of diagnosing multi-parameter systems of vehicle

*The object of research* is the process of technical maintenance of multi-agent systems.

*The subject of the research* is the process of quantitative evaluation and prediction of the risks of working capacity in the process of diagnosing vehicle multi-parameter systems.

To achieve goal the following aim is fulfilled in the article: sources of errors on the trajectory of the formation of the total measurement uncertainty were identified on the example of monitoring phase parameters of diesel engine fuel supply. A vehicle is considered as a complex multi-parameter multi-agent system with feedback to restore system performance. The control process is accompanied by errors in the form of a false and undetected defect. Probable errors determine risks of two types: risk of vehicle health checker and risk of a customer. For a quantitative assessment of these risks random and simulation models have been developed. Models allow to investigate the influence of statistical characteristics of modeling agents on control risks. For the integral assessment of the quality of maintenance, a "fuzzy" model and algorithm were developed by the example of the "personnel quality" criterion. Reliability and effectiveness of modeling is tested by a computer experiment based on a simulation approach. The developed mathematical model and simulation algorithm are universal and can be used in various scientific and technical practical applications. The authors proposed a new multi-approach method for quantitative assessment of decision-making risks in a multi-parameter control and management system using differentiated and integral functional indicators of the object under study.

**Key words:** vehicle, agent, system, model, probability, control, process, diagnostics, standard, accuracy, errors, risks.

**Introduction.** The performance of a complex system is an integrated composition of functional indicators taking into account the effects of the external environment [1-5]. The performance of the vehicle in accordance with the maintenance regulations is subject to periodic monitoring in order to quantify the compliance with the established standards (tolerances) of the current measured values of some of the most important technical and economic processes. From the stages of the car's life cycle, this paper considers the stage of its operation. From the point of view of system dynamics, this stage is a set of complex interconnected multi-agent processes United by a single goal [6]. In this composition of processes, it is necessary to distinguish the maintenance process (maintenance), which largely determines the economic, environmental and social indicators of vehicles. The main task is to maintain the operational reliability of the vehicle in the broad context of this requirement [7].

The maintenance process relies on knowledge from such subject areas as: mathematics, economics, management, diagnostics, ecology, computer science, artificial intelligence, etc. In this context, "agents" combine such properties and concepts as: software - hardware, technologically target entity; joint solution of a common problem through aggregation systems; inter-agent exchange of information and knowledge; providing local and aggregate robustness; modularity; system scalability and adaptability; multipath in the process of formalizing the functionality of agents; system openness [8,9].

The control system and support of the operational reliability of a vehicle should contain a monitoring that includes procedures (subprocesses) of measurement, comparison of the measured value with the normative meaning and decision making [9].The process of managing the operational reliability of a vehicle consists at least form the following agents: the object of control, control, analysis, decision-making and the agent for restoring the regulated functionality. The controlled parameters may have value of a specific physical quantity that in real conditions has a probabilistic nature, and be approximated by some distribution law *f(x)*. If it is not possible to measure a physical parameter directly we need to control its derivative called a diagnostic parameter S, which also has a probabilistic nature with a distribution density function *f(S)* [10].

**Scientific problem**. The measurement procedure in modern industrial and social technologies is often carried out by instrumental means, expert methods or their combination with technical means, and in some cases, especially in the control loop based on information systems that gives rise to the "human factor".

It is traditionally considered that the determining factor in the assessment of the reliability of control is the measurement error. But as it shown above, control is a complex systemic composition of agents with non-linear characteristics. An important condition in many well-known technologies for diagnosing road transport is the absence of standards, but the recommended technical conditions for carrying out diagnostic work and the regulatory framework are based on statistical data that suffer extreme heterogeneity, which makes the results of monitoring substantially uncertain. All of this led to the idea to use uncertainty as a measure of accuracy [11,13].

Modern methods of integrated assessment of vehicle performance include the use of complex diagnostic systems. Diagnostic algorithm appears to be a fuzzy multiparameter process. In such systems, a differentiated approach is used to assess the diagnostic qualities of the parameters according to their informativeness about the technical and economic performance of the engine. They are: environmental friendliness, connection with vehicle operational safety and fuel consumption. It is usual to proceed from their own experience and preferences to determine the optimal set of diagnostic parameters, especially in practice. Some studies recommend to use the methods of expert assessments and to determine the weight of individual diagnostic parameters. Therefore, there is a need to use some integral indicators calculated by factor aggregates using the fuzzy sets apparatus, leaned on linguistic qualitative assessments [9].

**Research methods.** A systematic approach was used as a methodological base for research. Within the scope of theoretical studies, scientific hypotheses were put forward, the purpose, criteria and objectives of research were determined. Formalization tool like a multi-approach methodology involving expert estimation, the theory of fuzzy sets, mathematical statistics, agent-based and simulation modeling are suggested. A wide range of sections including mathematical apparatus is because the task has a semi-structured and multifactorial type and the modeling is carried out under conditions of statistical uncertainty.

**Research result.** The model of structural uncertainty, based on the example of measuring the most important diagnostic parameter of a diesel engine - the fuel injection advance angle, is formed by the following sources: $\sigma_1$ - error of applying the base mark (marks on the crankshaft pulley); $\sigma_2$ - the error of applying the base label (marks on the crankcase); $\sigma_3$ - TDM sensor installation error; $\sigma_4$ - the error determined by the instability of the speed mode of rotation of the engine crankshaft; $\sigma_5$- error due to the dynamic instability of the fuel supply process; $\sigma_6$- error of visual fixation of dynamic marks (in stroboscopic measurements); $\sigma_7$ - error of reading information (in analog devices).

These structural components are of a statistical nature, independent and uncorrelated. The first two uncertainties are determined by factory documentation. Then, the resulting uncertainty is estimated from the expression $\sigma\Sigma = \sqrt{\{\sigma^2_i\}}$.

Control risk modeling with one limit standards. Let's consider some conventional complex multi-parameter system quality control. As functional processes, measurement and decision making are investigated. In this task, the control process is considered as a multi-agent system, where agents should be distinguished: agent - external environment; agent - object of control; agent - the measurement process; agent - standard consumption; agent - decision making system.

Process quality indicators, according to existing technical regulations, should not exceed some of the permissible standards. Standards (limits) can be one-sided (top or bottom) and two-sided. The case of two-sided limitation is called limiting.

Mandatory control procedure is measurement. Measurement is considered as an independent agent, which possesses characteristics independent in the control process - the distribution law and the corresponding statistical characteristics. During the research of a multi-agent system, these characteristics may vary in order to find the optimal values. This approach is applicable and to other agents.

The term and technological procedure “measurement” in this context can be understood broadly for any object (parameter, process, event) regardless of its nature [12]. Under the measuring instruments (meter, “device”) there can be physical instruments, instruments and methods of measurement, methods and resources for identifying data on documents, the subject and the resources used to identify the necessary information. The result of the measurement is always a number (or a set of numbers), giving a quantitative estimate of the measured value in some pre-selected units. The set of measurement results is the set of numbers from a certain range of possible values.

As shown above, control is a sequence of measurement procedures, comparing the measured value with the standards and making decisions based on the principle “a controlled object is suitable”, “a controlled object is unsuitable”. The final decision "suitable-unsuitable", as a rule, generally accepted by man.

Due to the fact that the measurement process is accompanied by random errors, control errors occur. Control errors are usually divided as false and undetected defects (false and undetected failures). Quantitatively, these errors are estimated by the corresponding probabilities, in this case, $P_{fd}$ is the probability of a false defect and $P_{ud}$ is the probability of an undetected defect. These probabilities are also sometimes given a sense of the risks of the producer of the work and the customer of the work, respectively.

In this way, initially there arises the general task of developing mathematical models for the quantitative estimation of these errors (risks) as a function of the statistical characteristics of all components of the multi-agent model: measurements, standards, and decision-making procedures. At the first stage of modeling it is considered that the standards are deterministic values.

For an integral assessment of the quality of measurement information, reliability as an indicator is often used. The reliability of the control is the degree of confidence that the measured values truly reflect the object's state of interest [9]. The expression for assessing the reliability is as follows:

$$D = 1 - (P_{fd} - P_{ud}).$$

The case of a single-limit restriction of the controlled parameter $S$ “from below” by the standard $S_n$ will be considered as the first variant of the model. From a probabilistic point of view, we will be interested in two events:

- the true value of the parameter is higher than the standard ($S_i > S_n$), i.e., the monitored parameter is normal (fit), and the measured value as a result of random error turned out to be lower than the standard ($S_{imeasur} < S_n$) (not valid), which is a false marriage;

- the true value of the parameter is lower than the standard ($S_i < S_n$), i.e., the monitored parameter is in the "invalid" field, and the measured value as a result of random error turned out to be higher than the standard ($S_{imeasur} > S_n$) (valid), which is an undetected marriage.

Initially assumed that distribution densities of the monitored parameter $f(S)$ and random error $j(y)$ are approximated by normal laws. Then the expressions for estimating the probabilities $R_{lb}$ and $R_{nb}$ will have the following form.

$$P_{fd} = \sum_{t=1}^{n} \frac{1}{\sqrt{2\pi}} \int_{t_i}^{t_{i+1}} e^{-\frac{t^2}{2}} dt \cdot \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z_i} e^{-\frac{z^2}{2}} dz \qquad (1)$$

The expression for estimating undetected defect $P_{nb}$ will be:

$$P_{ud} = \sum_{t=1}^{n} \frac{1}{\sqrt{2\pi}} \int_{t_i}^{t_{i+1}} e^{-\frac{t^2}{2}} dt \cdot \frac{1}{\sqrt{2\pi}} \int_{z_i}^{+\infty} e^{-\frac{z^2}{2}} dz \qquad (2)$$

The variable $t$ is a centered variable with respect to the average value of the monitored parameter and normalized with respect to the standard deviation (uncertainty). The variable $z$ is the normalized quantity with respect to the standard deviation of the density function of the measurement error distribution.

Analytical models (1) and (2) allow to investigate and quantify the impact of all statistical characteristics of the control system on the likely risks of $P_{fd}$, $P_{ud}$ and reliability $D$.

In the study of more complex processes, such as tolerance control, the probabilistic model is burdened by additional sources of computational errors. In this case, the most acceptable and effective method for modeling control errors under tolerance standards, as established by the authors, is the use of simulation modeling. The simulation model algorithm for this case contains:

The first block is the input of the initial statistical characteristics of the laws of distribution and the number of simulation cycles - $N$. The second, third and fourth blocks, as follows from the explanations in the blocks, are random number generators. Blocks 5 and 6 contain the logical condition $IF$ (branching) $V_l < V_i < V_u$ and $V_l < V_{imea} < V_u$.

Blocks 7 and 9 are event counters. In block 10, the calculation of the risks of $R_{fd}$ and $R_{ud}$ is carried out, and in block 11, the integral indicator of the quality of control is calculated - reliability.

In the results of a computer experiment, it was found that the probability of a false defect of $R_{fd}$ is most affected. If the value of measurement uncertainty $\sigma_\varphi$ is comparable with the value of $\sigma_s$, the risk can reach 25%. At the same time, it was found that the impact of variation in standards on reliability is significantly higher than the effect of measurement uncertainties. Analysis of the simulation data showed that the systematic relationship of the statistical characteristics of the process and control parameters leads to non-linear results and eliminates the possibility of linear quantitative predictions of reliability and control risks. Effective design of such systems is provided by formal methods implemented in the form of software applications. The results obtained are extremely important when choosing alternatives in the control paradigm, it means which one should prefer the accuracy parameters of the instruments or the regulatory framework.

Based on the research results, the following conclusions can be drawn:

To control the quality of decision making in a complex multi-parameter system, to increase the reliability and efficiency of this process, it is necessary to involve formal mathematical and simulation methods. In the quality management of multi parameter systems, the control process plays a crucial role, at which stage management risks are formed. It is rational to control by two algorithms: differentiated according to the set of indicators of the quality of system functioning and on the basis of an integral indicator that aggregates differentiated estimates in the form of convolution. The control contains procedures: measurements, comparison of the measured result with the standard, decision making. Risks are control errors and are quantified by the probability of a false defect and the probability of an undetected marriage. For the quantitative measurement of control errors in the work, probabilistic and simulation models of estimating confidence, as well as false and undetected defects are proposed. For theoretical modeling and practical use in the design of complex diagnostic systems, a software package has been developed. The results of computer simulation showed the following:

1. The analysis of computer-aided customer risk assessment data also confirms the presence on the surface of the response line of the maximum, passing for the case of a normal distribution of $Y$ and $S$ at values of 10.58%, 16.5%, 25.95%, 27.05%, 29.63%, 31.3%. For the case of the distribution of $Y$ under the normal, and S under the uniform laws, the maximum values are 5.5%, 11.5%, 14.5%, 16.9%, 18.8%, 21.3%.

2. Simulation of the manufacturer's risk level confirms that there is a maximum value that corresponds to the values of 10.85%, 19.25%, 23.9%, 28.85%, 30.8%, 34%, but for the values of $S_{av}$, equal to 1.3 and 1.4. For the case of a normal distribution of $Y$ and $a$ uniform distribution of $S$, the maximum values are 5.9%, 12.4%, 19.4%, 25%, 29.6%, 29.7%, respectively, to the levels of variation indicated above. The maximum corresponds to the average value of $S$, equal to 1.5.

3. The loss level for the uniform distribution law $S$ is lower than for the normal law and the maximum value shifts towards a larger value of the average value $S$, which has a certain economic meaning in the process of implementing the decisions. The mathematical explanation of the presence of mini - max levels can be considered as a consequence of the conjugation of two smooth nonlinear forms, as a result of which a third, clearly nonlinear form is generated.

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# АВТОМОБИЛЬДІҢ КҮРДЕЛІ ЖҮЙЕЛЕРІНІҢ ЖҰМЫСҚА ҚАБІЛЕТТІЛІҒІНІҢ МУЛЬТИКӨРСЕТКІШТІК БАҚЫЛАУЫНЫҢ САПАСЫН БАҒАЛАУ

**Аннотация.** *Зерттеудің мақсаты* автомобиль жүйелерінің көпкөрсеткіштік диагностикалауының тәуекелдігін болжау мен сандық бағалау болып табылады.

*Зерттеудің нысаны* көпагенттік жүйелердің техникалық қамтамасыз етуінің үрдісі болып табылады.

*Зерттеудің пәні* автомобильдің көпкөрсеткіштік жүйелерін диагностикалау үрдісіндегі жұмысқа қабілеттілікті бақылау тәуекелдігін болжау мен сандық бағалау үрдісі болып табылады.

Қойылған мақсатқа жету үшін мақалада міндеттер шешілді: дизель қозғалтқышының отын беруінің фазалық көрсеткіштерін бақылау мысалында өлшеудің жиынтық белгісіздігін қалыптастыру траекториясында дәлсіздік көздерін анықтаған.

Техникалық қызмет көрсету регламенттеріне сәйкес автомобильдің жұмысқа қабілеттілігі кейбір негұрлым маңызды техникалық-экономикалық үрдістердің ағымдағы өлшенетін мәндерінің белгіленген нормативтерге (рұқсаттарга) сәйкестігін сандық багалау мақсатында агымдық бақылауга жатады. Бұл жұмыста автомобильдің өмірлік циклінің кезеңдерінен оны пайдалану кезеңі қарастырылады.

Бақылау үрдісінің алгоритмі бақыланатын көрсеткіштің қасиеттері мен мәндеріне, нормативтік мәндерге, талдау әдісі мен құралдарына және шешім қабылдау жүйесіне байланысты болады. Егер нормативтік функцияларды қалпына келтіру қажеттігі туралы шешім қабылданса, онда объектіге кері байланыс нысанында реттеу (түзету) әсері қолданылады. Кері байланыс барлық техникалық қызмет көрсету үрдісінің түпкілікті нәтижелілігін анықтайды, өйткені кері байланыссыз басқару барлық мағынасын жогалтады және болып жатқан жағдайды жай гана ойлауга айналады.

Автомобильге техникалық қызмет көрсетудің соңғы нәтижесі пайдалану сенімділігін арттыруга, экологиялық қауіптілікті төмендетуге және үнемділігін арттыруга бағытталуы тиіс. Көпкөрсеткіштік диагностика осы міндеттерді шешудегі тиімді құрал болып табылады. Сонымен қатар, жогарыда көрсетілген өлшемдер бойынша диагностикалық кешенді объективті таңдау әдістемесі іс жүзінде жоқ. Келтірілген мәселе бойынша шешім қабылдаудың объективтілігі мен сапасы қолда бар техникалық базаны пайдалану тәуекелдерін багалауга және зерттелетін мәселені шешуде инновациялық техникалық-ұйымдастырушылық тәсілдерді енгізу кезінде оларды болжауга мүмкіндік беретін формальды құралдарды енгізу жолымен жогарылауы мүмкін.

Күрделі көпкөрсеткіштік жүйеде шешім қабылдау сапасын басқару, осы үрдістің нақтылыгы мен жеделдігін арттыру үшін формальды математикалық және имитациялық әдістерді тарту қажет. Көпкөрсеткіштік жүйелердің сапасын басқаруда бақылау үрдісі шешуші рөл атқарады, оның кезеңінде басқару тәуекелдері қалыптасады.

Автомобиль, жүйенің жұмысқа қабілеттілігін қайта қалпына келтіру мақсатында кері байланысы бар күрделі көпкөрсеткіштердің көпагенттік жүйе ретінде қарастырылады. Бақылау үрдісіне жалган және табылмаган ақау түріндегі қателер жатады. Ықтимал қателер екі түрдегі тәуекелдерді анықтайды: диагностикалық жұмыстарды өндірушінің тәуекелі және жұмыстарга тапсырыс берушінің тәуекелі. Көрсетілген тәуекелдерді сандық багалау үшін ықтималдық және имитациялық үлгілер жасалынды. Үлгілер үлгілеу агенттерінің статистикалық сипаттамаларының бақылау тәуекелдеріне әсерін зерттеуге мүмкіндік береді. Техникалық қызмет көрсету жүйесінің сапасын интегралдық багалау үшін «анық емес» үлгі және «персоналдың сапасы» критерийі мысалында алгоритм әзірленді. Үлгілеудің дұрыстыгы мен нәтижелілігі имитациялық тәсіл негізінде компьютерлік экспериментпен тестіленеді. Әзірленген математикалық үлгі және имитациялық алгоритм әмбебап сипатқа ие және әртүрлі гылыми-техникалық тәжірибелік қосымшаларда қолданылуы мүмкін. Авторлармен зерттелетін объектінің дифференциалды және интегралды функциональдық көрсеткіштері бойынша көппараметрлік бақылау және басқару жүйесінде шешім қабылдау тәуекелдерін сандық багалаудың жаңа көптәсілді әдістемесі ұсынылды.

**Түйін сөздер:** автокөлік, агент, жүйе, үлгі, ықтимал, бақылау, үрдіс, диагностика, нормативті, шынайы, қателер, тәуекел.

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## ОЦЕНКА КАЧЕСТВА МУЛЬТИПАМЕТРИЧЕСКОГО КОНТРОЛЯ РАБОТОСПОСОБНОСТИ СЛОЖНЫХ СИСТЕМ АВТОМОБИЛЯ

**Аннотация.** *Целью исследования* является количественная оценка и прогнозирование рисков диагностирования многопараметрических систем автомобиля.

*Объектом исследования* является процесс технического обслуживания многоагентных систем.

*Предметом исследования* является процесс количественной оценки и прогнозирования рисков контроля работоспособности в процессе диагностирования многопараметрических систем автомобиля.

Для достижения поставленной цели в статье решены задачи: выявление источников погрешностей на траектории формирования суммарной неопределенности измерения на примере контроля фазовых параметров топливоподачи дизельного двигателя.

Работоспособность автомобиля в соответствии с регламентами технического обслуживания подлежат периодическому контролю с целью количественной оценки на соответствие установленным нормативам (допускам) текущих измеряемых значений некоторых наиболее важных технико-экономических процессов. Из этапов жизненного цикла автомобиля в данной работе рассматривается этап его эксплуатации.

Алгоритм процесса контроля зависит от свойств и значений контролируемого параметра, нормативных значений, метода и средств анализа и системы принятия решения. Если принимается решение о необходимости восстановления нормативных функций, то предпринимаются регулировочные (корректирующие) воздействия на объект в форме обратной связи. Обратная связь определяет конечную результативность всего процесса технического обслуживания, так как без обратной связи управление теряет всякий смысл и превращается в созерцание происходящего.

Конечный результат технического обслуживания автомобиля должен быть нацелен на повышение эксплуатационной надежности, снижения экологической опасности и повышения экономичности. Многопараметрическая диагностика является в некотором объеме эффективным инструментом в решении этих задач. Вместе с тем, методика объективного выбора диагностического комплекса по указанным выше критериям практически отсутствует. Объективность и качество принятия решения по приведенной проблематике может быть повышены путем внедрения формальных инструментов, которые предоставят возможность оценивать риски использования имеющейся технической базы и прогнозировать их при внедрении инновационных технико-организационных подходов в решение исследуемой проблемы.

Для управления качеством принятия решений в сложной многопараметрической системе, повышения достоверности и оперативности этого процесса необходимо привлекать формальные математические и имитационные методы. В управлении качеством многопараметрических систем решающую роль играет процесс контроля, на этапе которого формируются риски управления.

Автомобиль рассматривается как сложная многопараметрическая многоагентная система с обратной связью с целью восстановления работоспособности системы. Процессу контроля сопутствуют ошибки в форме ложного и необнаруженного брака. Вероятные ошибки определяют риски двух типов: риск производителя диагностических работ и риск заказчика работ. Для количественной оценки указанных рисков разработаны вероятностные и имитационные модели. Модели позволяют исследовать влияние статистических характеристик агентов моделирования на риски контроля. Для интегральной оценки качества системы технического обслуживания разработана «нечеткая» модель и алгоритм на примере критерия - «качество персонала». Достоверность и результативность моделирования тестируется компьютерным экспериментом на базе имитационного подхода. Разработанная математическая модель и имитационный алгоритм носят универсальный характер и могут использоваться в различных научно-технических практических приложениях. Авторами предложена новая многоподходная методика количественного оценивания рисков принятия решений в многопараметрической системе контроля и управления по дифференцированным и интегральным функциональным показателям исследуемого объекта.

**Ключевые слова:** автомобиль, агент, система, модель, вероятность, контроль, процесс, диагностика, норматив, достоверность, ошибки, риски.

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