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OBJECT CHARACTERISTICS DETERIORATION EFFECT ON TASK REALIZABILITY – OUTLINE METHOD OF ESTIMATION AND PROGNOSIS

ZARYS METODY OCENY TRWAŁOŚCI I NIEZAWODNOŚCI OBIEKTU Z UWZGLĘDNIENIEM CZYNNIKA LUDZKIEGO I PŁASZCZYZNY LICZB ZESPOLONYCH*

The article introduces the essence of a potential technical object work range. Vital issues connected with the modeling of an object work range deterioration which are influenced by the destructive processes derived from environment, operation and wear of the object, were discussed/described. Typical destructive processes were described and deterministic and probabilistic models which allow for evaluation and prognosis of an object durability were included in the description. An outline of the approach to object work range deterioration adopted by the authors was presented. An outline of an object condition models for evaluation and prognosis of its durability purposes including a complex issues of random influence of the many factors which affect changes in an object work range and influencing the quality of the performed tasks were shown. In the models including randomness, probabilistic tools/apparatus and fuzzy logic were adopted. This kind of approach in modeling the changes in object durability adopted by the authors aims at bringing the models of object durability change closer to operational reality and at the same time at better utilization of their potential work range while maintaining the assumed level of reliability/safety during operations.

Keywords: object work range, reliability, durability, material consumption, modeling, calculus of probability, fuzzy logic, efficiency, destructive processes.

W artykule dokonano wprowadzenia w istotę pojęcia tzw. potencjalnego zasobu pracy obiektu technicznego. Opisano istotne zagadnienia związane z modelowaniem zużywania zasobu pracy, na które wpływają procesy destrukcyjne od środowiska, użytkowania i obsługi. Wskazano na typowe procesy destrukcyjne i dla nich przedstawiono modele deterministyczne i probabilistyczne umożliwiające ocenę oraz prognozę zużywania potencjalnego zasobu pracy obiektu dla przyjętego poziomu niezawodności lub trwałości obiektu. Przedstawiono też zarys realizowanego przez autorów podejścia w modelowaniu zużywania zasobu pracy obiektu. Pokazano zarys modeli stanu obiektu do oceny i prognozy jego trwałości z uwzględnieniem zagadnień losowego wpływu wielu czynników wpływających na zmianę zasobu pracy obiektu, a tym samym, na jakość realizowanych zadań. W modelach uwzględniających losowość przyjęto aparat probabilistyczny oraz wykorzystano logikę rozmytą. Tak przyjęte przez autorów podejście w modelowaniu zmian niezawodności/trwałości obiektu, ma na celu lepsze przybliżenie do rzeczywistości eksploatacyjnej, a tym samym lepsze wykorzystanie ich potencjalnego zasobu pracy, przy zachowaniu założonego poziomu niezawodności/bezpieczeństwa w trakcie realizacji działania/uzyskania efektu. Na koniec pokazano nowatorskie na skalę światową podejście, pozwalające na łączenie w jednym modelu technicznych i nietechnicznych aspektów oceny i prognozy zmian jakości obiektów w eksploatacji poprzez wykorzystanie do tego celu płaszczyzny liczb zespolonych.

Słowa kluczowe: Eksploatacja, zasób pracy obiektu, niezawodność, trwałość, zużycie, modelowanie, probabilistyka, logika rozmyta, efektywność, procesy destrukcyjne

1. Introduction

For the object holder its work potential, during maintenance process (achieving particular aim) is very important factor. What is more object potential consumption during maintenance procedures, storage and waiting for the execution of the next task is also significant.

For precise defined condition of an object assignment, work potential resource determines its maximum durability achievement (maximum usage of work resource maximum durability)¹. Object work resource consumption leads to (at the beginning usually in hidden way) object parameters deterioration (necessary during useful object maintenance process).

¹ Durability is the ability to endure; it is object ability to maintain its material and structural property (taking into account the maintenance process including parts replacement) which allows to reliable work.

There are two main strategies dealing with a problem. The first one is implementation of the object reconditioning (refurbishment) process (totally or partially). The second strategy is object consumption effects acceptance and use that knowledge in the current assessment and further object work resource prediction. Both strategies need controlling/measuring/ monitoring of the object consumption process. Also need evaluation and prediction methods of the process influence on work resource decreasing and malfunction probability increasing. This approach is significant for objects/systems where reliability and safety are crucial factors.

What we perceive as our material world has one essential property: independent from whether a given technical object² is used or not, destructive processes take place in the object and change its properties. It means that the process which leads to diminishing the ob-

² Further called object.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie www.ein.org.pl

jects potential work range determined during design stage takes place constantly. For various objects (and within the objects for modules/assemblies) depending on environmental conditions change, changes in operational and maintenance intensity, as well as the quality of the object itself (material, constructional and technological) achieved during its development, both the rate and direction of destructive changes are different. Such situation generates various consequences affecting both the object, as well as us that is the operators or owners of the object. This variability can be really significant for the same class objects of the same utility e.g. service life, as well as for an individual object during its task performance measured in time, rotations/revolutions, work cycles, or kilometers. It can lead to more or less serious consequences such as underestimating the rate of the object wear, damage causing stopovers at work, failures generating financial losses, or catastrophes even [3]. The significance of the variability acquires additional meaning, especially when the variability leads to a catastrophe or significant financial or social losses. Predicting the consequences of these changes, preventing them and including them in planning your economic or social activities is one of the essential tasks in design and operation analysis of an object life cycle.

In various technical object definitions, an operator of the object is included or not. It seems indispensable to include an operator/user as an element of the object constituting the whole and analyses operator's capabilities and influence on the object reliability and durability. Especially that usually the objects are integral part of bigger systems, like maintenance systems where technical and human factors are actually connected³. Where it is proven/indicated that the capabilities of the operator are not sufficient to perform the tasks in a safe manner, systems replacing human/operator are applied and technical safety engineering deals with the problem [17].

Proper process models are designed for destructing development analysis of assumed (predicted) loads⁴. Variables minimalizing, assuming typical loads and deterministic models (like constant human factor) provide reality simplification, but can be only used in object stationary processes and object environment. In most cases, destructing process models should comply more complicated dependence, taking into account overloads (normal load level exceeded) [13].

Appropriate/adequate, correct model of destructive processes should include weak sides of the object and should be a clue for designers to include inherent object properties [4, 17] leading to minimizing the negative results when encountering excessive loads (e.g. by switching off the object or switching I protective alarm systems). To build such models it is necessary to apply mathematical tools/apparatus [22] which will enable among other things incorporating probability, using partial operational data (diagnostic systems); including influence on human factor process and will include limit values of the process. The issue is not simple. Attempts to implement the above have been undertaken in many works [7, 16, 23] however so far these have been attempts comprising detailed/separate cases of destructive processes, and they lacked comprising both the mechanical causes and the human factor, which can have vital influence on the rate of change (malfunctions, crashes).

Indeterminacy/uncertainty of the object data (where there are no statistical data) cause use fuzzy logic possible in those data evaluation process. There are existing examples of fuzzy logic use in structural reliability analysis, mechanical vibration components [6, 24], reliability improvements estimation during product development [25] and maintenance planning of cold plastic deformation tools [1]. Unfortunately, each of those models do not provide a full picture of object quality and information about all object work resources changing

causes. That is why, authors, decided to develop a model and description method based on fuzzy logic theory, probabilistic calculation and the theory of complex numbers⁵.

The essence of the model and method is use of:

- probabilistic modeling of changing parameters which decide about technical object evolution (concerned with object inherent properties) to evaluation and prediction of object quality⁶,
- fuzzy logic theory (fuzzy inference) for changing parameters description concerns with maintenance organization, environmental condition and standard of use volatility,
- theory of complex numbers to final evaluation/prediction indicator description (quality/use of objects/systems work resources and technical/non-technical object changes influence analysis).

Authors inspiration became searching of more adequate models/methods of objects/systems quality evaluation and prediction which are required, especially in safety reports [4]⁷. The main purpose of report [4 p. 8] is presentation that danger of serious failures is identified and all indispensable measures were made to eliminate malfunctions and its influence on people and environment safety. Moreover proper safety and reliability solutions are put into effect during designing, maintenance and conservation of every installation.

2. Outline of methods of assessment and prognosis of object properties deterioration influence on task performance capabilities

The complete model of object/system work resources changing process or transition in state of unable to work (especially malfunctions lead to failures and crashes), should take into consideration inherent and not inherent features.

Object/system work resources changes from inherent features are for example:

- linear or volumetric effects of material deterioration (usage and age);
- deregulation (resulting from vibrations and strikes);
- change in primary characteristic of the object/system after production process and maintenance implementation;
- changes in power supply parameters (electrical, hydraulic).

Object/system work resources changes from not inherent features depend on:

- change in load (as a result of task type change);
- change in operation and maintenance quality,
- change of the working environment, etc.;

what is caused by:

- constancy or inconstancy of usage norms;
- variability of the working agent used in the object (e.g. material parameters of turning-lathe machined parts or types of projectiles used in weapons, voltage and current value for mechatronic and digital devices);
- quality of operation (propriety of starting and shutting down, complying to the accepted usage proprieties);
- natural environment parameters variability gradients (temperature – magnitude and the gradient of change in time, humidity, dusting/sanding);
- artificially induced threats e.g. air defense reaction or surges in the mains caused by switching on and off of big receivers or power suppliers;
- the quality of maintenance (applied strategy of operation, personnel qualifications, diagnostic tools, compliance to and quality of the procedures, used materials).

³ People (operators/users, maintenance personnel, etc.) behave differently and it causes bringing in unreliability in correct object work changes in object work life.

⁴ In human factor contexts destructive loads could be inappropriate organization change, change of maintenance personnel training level, do not take into consideration changing environmental condition of personnel work which decreasing their work capability.

⁵ Authors have no knowledge about research concern using of theory of complex numbers in described matters.

⁶ Object characteristic properties are: reliability, durability, readiness, efficiency, safety, etc.

⁷ That kind of reports must be realized in Seveso factories [16].

Usually causes changing of not inherent features are defined for normal/typical conditions which are unrealistic and can be estimated only by experts.

Therefore inherent features are changing randomly and are described by many variables random functions. Important are only those which change can be used in diagnostics measurements and during maintenance procedures.

So the Authors main goal is recognition of elements (object) properties, that changes have significant influence on object/system features changes and cause object work variation.

Requirement is necessary to record the changes during diagnostic maintenance and provide economically rational profit.

Record the features changes (with use of adequate evaluation and prediction methods) provides information used in decision-making process:

- its work range at the moment of diagnostic examination (its work capacity analysis),
- its residual durability/lifetime (for new objects its overall durability/stability),
- rate of deterioration of the object work range (change of residual durability) for the assumed often changeable operational conditions (change of work standards, operational and environmental conditions),
- when the object should be subjected to maintenance preventing damage (especially the damage leading to failures or crashes/catastrophes) that is to say maintenance which restores completely or partially original object properties,
- the relationship between object/elements properties deterioration (between object maintenance or replacement) and its operational efficiency and the losses generated in relation to a new object.

In conclusion the Authors search the object/system model with changing object parameters (changing because of object features lost depends on its inherent and non-inherent characteristic) on the input. Parameter presents performing tasks possible change, described by evaluation or prediction of an object rest of work resources or changing probability of failures (especially malfunctions lead to failures and crashes) should be on the output.

2.1. Models of processes relevant to object work range

Evaluation or prediction methods of influence object deterioration features on the possibility of tasks implementation request to completion of partial tasks listed below:

- modeling process concerns work resources and its decreasing causes,
- project of mathematical model used to calculate influence of object destructive changes on work resources with incomplete/random data which provides as the effect dependence of work resources change and selected diagnostic parameters,
- project of model transforming measuring and estimating results into hints as possible maintenance decisions,
- project of databases model which provides object data transferring automation process into accepted maintenance/management decisions.

Processes modeling and object maintenance data transferring model designing are presented in this publication. Fig.1 presents schematically representative processes impacting the work range of an object. Object properties, object utility (degree of task performance capability), work and environment load as well as the quality of maintenance and quality of parameters describing properties change in the function of work range deterioration and its influence on performed task efficiency were included.

A scheme, known from automation, of inputs and outputs analysis can be applied here. There are two basic types in the scheme:

- I The object is treated as the black box.
- II The object model is presented with the use of known mapping/imaging/representation e.g. its reliability, functional structure.

The first model is usually applied where we have no data concerning the internal structure of the object or the structure is so complex/numerous (e.g. a processor) that its analyzing according to the second type is either unattainable or too expensive. Difficulty in adopting this approach lies in proper selection of input and output parameters that is such parameters whose change reflects the factual change of the object properties which are of interest to us.

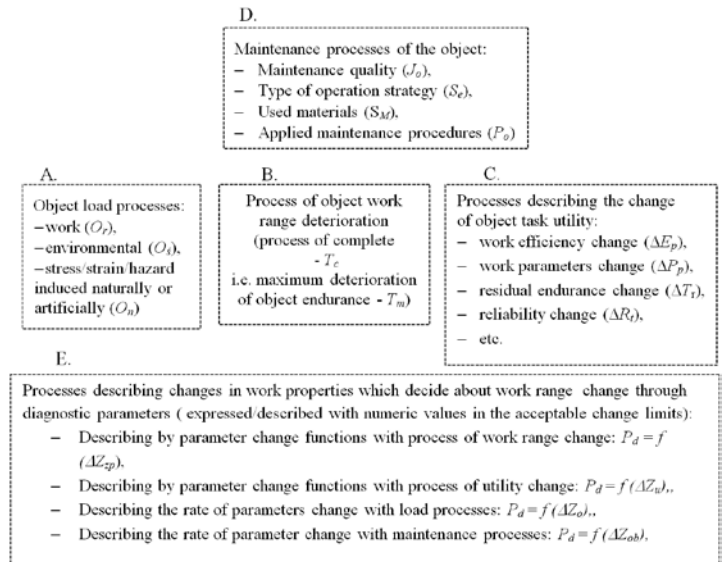


Fig. 1. Representative processes impacting the change of object work range ((ΔZ_{zp}))

The second model is used where the change in internal parameters cannot be observed through the analysis of inputs and outputs (the observed effects are stoppages and failures) and the lack of monitoring of the changes can lead to uncontrolled damages which can be the cause of an object failure as well as crashes. It is essential, in both models, to follow changes, transform input parameters into output parameters, steering the rate of output parameter change processes through limiting input/ interference changes.

2.1.1. General outline of the model I

A very general model of object work range change can be expressed by the relationship (1):

$$\Delta Z_{zp} = f(\Delta A; \Delta B; \Delta C; \Delta D; \Delta E) \tag{1}$$

in which:

- ΔZ_{zp} – object work range change;
- f(ΔA; ΔB; ΔC; ΔD; ΔE) – function transforming parameters in Fig.1 change to a change of object work range;
- ΔA; ΔB; ΔC; ΔD; ΔE – Fig.1 parameters change.

Knowing the transformation function and the parameters change it is possible to follow the changes in the object work change. If, in an object population, parameters of change are known then based on that application of objects to different tasks can be predicted. This type of modeling does not allow for strategy realization in accordance with the objects technical condition but only better assessment of its life-time and better utilization of object work range while realizing the strategy of planned prevention.

2.1.2. General outline of model II

Modeling according to type II allows for the realization of operational strategy according to an object technical condition. In this model, mathematical models of Fig.1 processes were represented/expressed as a set of relationships (2÷6) for (A, B, C, D, E).

$$A = f(O_r, O_f, O_n) \tag{2}$$

$$B = f(T_c, T_m) \tag{3}$$

$$C = f(\Delta E_p, \Delta P_p, \Delta T_r, \Delta R_t) \tag{4}$$

$$D = f(J_o, S_e, S_M, P_o) \tag{5}$$

$$E = f\{[P_d = f(\Delta Z_u)]; [P_d = f(\Delta Z_o)]; [P_d = f(\Delta Z_{ob})]\} \tag{6}$$

The essence of object condition assessment and prognosis in these models is connecting measured object physical changes with the load causing the changes and the parameter describing the object work range changes e.g. the number of completed work cycles, mileage or object work time/period. Based on the changes and adopted acceptable limit values, life cycle of an object can be managed by introducing it into proper modes e.g. operation, servicing or withdrawal/retirement/ change of application/ condemnation.

2.1.3. Summary

Modeling of this type is simplified through the adoption of the assumption that changes take place in deterministic unambiguous way and in homogeneous operational conditions and environment load and that all the factors impacting object work range changes are known. When the conditions are scarce or dominating conditions exist, such approach brings sufficient results. In other cases probabilistic model, which deals with random variables in the form of possible events distribution instead of events should be adopted.

2.2. Outline of the method employing probabilistic models

For complex objects (functional and consumption of the objects elements process complexity) state of the elements can cause object transition into different technical state and necessity of probabilistic calculation use for object description and search optimal maintenance strategy [11, 21, 22].

The outline of the method is presented based on the described general [22] and detailed [7, 23] models of objects such as aircraft gun, fast firing automatic cannons as well as operational systems of the object and methods of technical object management [18], audit, endurance and reliability assessment [14].

Of all the elements of object operational process, parameters characterizing them are singled out and their space-time composition is created. The essence of the structure research is defining the mutual relationship and acceptable limits of individual parameters in relation to others changes.

The presented main idea of mathematical modeling of technical object operational process assessment has been based on the following assumptions:

- each isolated element of operational process can be presented in the form of parameters set;
- there are many factors impacting individual parameters changes and none of them is dominating;

- changes in the values of the parameters adopted for the assessment assess the elements unambiguously by defining the brackets of acceptable change values in the process of their operation;
- there exists a result parameter which describes the given element in the operational process in an unambiguous manner.

Because of random character of the changes, a mathematical model which uses differential equation describing the dynamics of technical object condition change (7) [7, 22, 23], has been proposed

$$\frac{\partial U}{\partial N} = -b_1 \frac{\partial U}{\partial Z_1} - b_2 \frac{\partial U}{\partial Z_2} - \dots - b_n \frac{\partial U}{\partial Z_n} + \frac{1}{2} \left(a_1 \frac{\partial^2 U}{\partial Z_1^2} + a_2 \frac{\partial^2 U}{\partial Z_2^2} + \dots + a_n \frac{\partial^2 U}{\partial Z_n^2} \right) \tag{7}$$

where:

$$\begin{matrix} b_1 = \lambda \cdot {}_1h_1 & a_1 = \lambda \cdot {}_1h_1^2 \\ b_2 = \lambda \cdot {}_2h_2 & a_2 = \lambda \cdot {}_2h_2^2 \\ \vdots & \vdots \\ b_n = \lambda \cdot {}_nh_n & a_n = \lambda \cdot {}_nh_n^2 \end{matrix}$$

In (7) coefficient b1 means average individual parameters value increase in the work cycle unit e.g. firing and coefficients a1 mean average square of parameters value increase in the unit of firing. The solution of the problem has the form:

$$U(Z_1, Z_2, \dots, Z_n; N) = \prod_{i=1}^n g_i(Z_i, b_i, a_i) \tag{8}$$

where:

$$g_i(Z_i, b_i, a_i) = \frac{1}{\sqrt{2\pi} \cdot a_i N} e^{-\frac{(Z_i - b_i N)^2}{2a_i N}} \tag{9}$$

A practical solution can be offered by estimating the parameters of probability distribution with the use/application of e.g. credibility function. Thus for the newly introduced technical object, the final expression of its endurance is described by the formula [7, 23]:

$$N_i = \left(\frac{-\alpha_i \cdot \sqrt{a_i^*} + \sqrt{4 \cdot b_i^* + \alpha_i^2 \cdot a_i^*}}{2 \cdot b_i^*} \right)^2 \tag{10}$$

where: α_i – change limit value.

Using the essence of the model for a technical object, models precisely allowing for:

- rational planning of object maintenance activities in relation to the conditions of its operation,
- predicting stocking of spare parts in relation to operation conditions (maintenance and operation) [7, 23],
- prolonging the life-cycle of serviceable technical objects can be developed [7, 18, 23].

3.3. Outline of fuzzy inference system model

The method utilizing models of fuzzy logic has been developed on general models presented in works/papers [5, 9, 19, 20] and detailed models of objects [5, 15, 26] such as e.g. aircraft guns, operational systems of the objects as well as management methods, audit and evaluation of the technical objects efficiency [1, 6, 24, 25]. Using fuzzy logic, a model of fuzzy reasoning representing properties which

are of interest to us can be developed. The basis for the model is the concept of information fuzzy coding. They function/operate on fuzzy sets instead of numbers, which allows for the generalization of the information. There are two basic models of fuzzy inference:

- non-adaptive inference (the parameters and structure of the model established in the design process remain unaltered during its operation);
- adaptive inference (the parameters and structure of the model established in the design process undergo changes during its operation/functioning).

Non-adaptive inference is simpler than the adaptive one but requires greater knowledge about the steered/managed object and can produce worse performance indicators.

Figure 2 presents the scheme of fuzzy inference system.

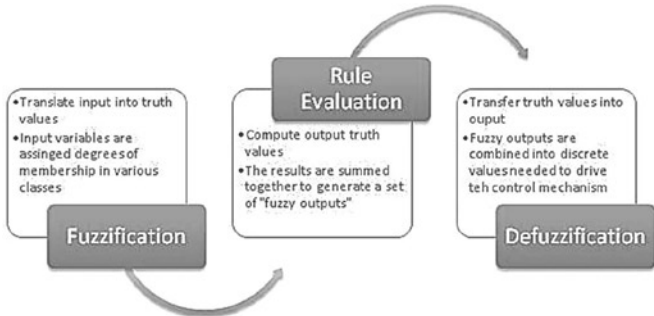


Fig. 2. Fuzzy inference system model

The model of fuzzy inference is based on three major blocks (fig. 3):

- Fuzzification block referred to as fuzzificator,
- Inference block with rules database,
- Defuzzification block referred to as defuzzificator.

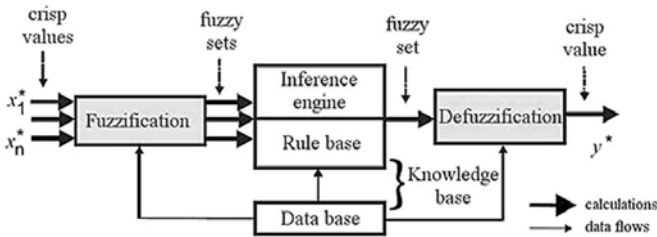


Fig. 3. Fuzzy inference system with fuzzificator and defuzzificator blocks

Usually on the **fuzzificator** input (fig. 3) determined values are given/fed (crisp: $x_1 \div x_n$), which are transformed into fuzzy variables i.e. the numerical value of membership function is obtained, $\mu(x_A)$, $A \in \{1, N\}$ for $x_A \in X_A$. Calculated and given on the output, values of membership degree provide information about how high is the membership of input values in relation to individual fuzzy inputs sets.

Inference block contains/includes (fig.3):

- rules database (contains the main part of knowledge about the system being modeled, therefore the capability to design this part properly is essential);
- inference algorithms;
- variable membership functions and generates fuzzy set for variable y.

Result membership function often assumes a complex shape and it is calculated by inference which can be mathematically realized in many different ways.

Methods of inference can be derived from a number of sources:

- expertise (an expert based on his accumulated prior experience, defines modus operandi for individual cases, which may take

place during the process – the expert’s task then will be to design the inference rule itself as well as to select membership function for each individual case;

- qualitative model;
- automatic knowledge accessibility/extraction algorithms.

Inference based on expertise is predicate on knowledge and experience of a person familiar with the idiosyncrasy of the designed system. Here the explicit and tacit knowledge can be differentiated. The explicit one is characterized by the fact that it can be expressed verbally by the expert and thus transferred to another person. Tacit knowledge on the other hand cannot be formulated [5,19]. This knowledge is manifested during practical maintenance activities of a system (e.g. using aircraft weapons). By interviewing experts only formal part of knowledge about the system can be obtained from them in the form of verbal rules illustrating the input/output relationships of type:

$$\text{When } (x_1 \text{ is } A_n) \text{ and } (x_2 \text{ is } B_n) \text{ then } (y \text{ is } C_m), \quad (11)$$

where: x_1, x_2 – system inputs, y – output,

A_n, B_n, C_m – fuzzy sets applied in linguistic assessment of system inputs and outputs [5].

The example of the inference process realization (based on MODUS PONENS rule) is presented in the table 1.

Table 1. Inference process realization based on MODUS PONENS rule.

A	highly efficient aircraft armament
IMPLICATION	if highly efficient aircraft weapons are used then the probability of combat task execution increases
B	high probability of combat task execution

The set of verbally formulated rules defining the input/output relationship and the set of verbal information of linguistic values as used by an expert is called a verbal model. Verbal model is usually more modest than mental model as it does not include tacit knowledge about the system, which an expert is not able to transfer [5, 19]. The information flow taking place in the process of fuzzy linguistic system model creation is presented in Fig. 4.

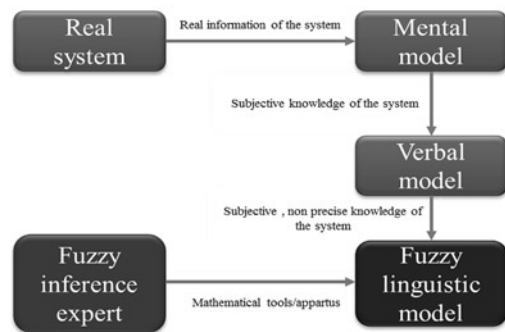


Fig. 4. Process of creating fuzzy linguistic model of the realistic system

Result function in the defuzzificator (fig. 3) is converted into determined variables (defuzzification) y.

Among many defuzzification methods the most known ones are:

- “Middle of Maximum” – MOM,
- “Smallest of Maximum” – SOM,
- “Largest of Maximum” – LOM,
- “Center of Gravity” – COG,
- “Center of Sums” – COS,
- “Height Method” – HM.

Modeling of the type allows for the assessment and prediction of the objects condition in the situations when because of the lack of other possibilities we need to seek help in experts’ opinions and

especially the so called intuitive aspects of these opinions deriving more from the combination of their accumulated experience and inner intuition in the given field. In some situations it is the only method in some other it is the most efficient or the fastest method to assess and predict object work range deterioration for the preliminarily defined rules of the object operation, maintenance and given environmental conditions.

2.4. Object maintenance quality model with use of complex numbers

According to European data [4], the importance of limitations/threats comes from human factor is increasing in system designing processes. And that is why civilian and technical safety engineering starts developing.

Very important conclusion is provided in this publication: the theory about mathematical dependence between technical and non-technical aspects of object work resource consumption is required for further model analysis and research of object work resource effective use process with assumed/accepted/required level of reliability or durability.

To do so, Authors propose (the world innovation) using complex numbers theory [10] in object maintenance quality modeling. It consists of technical and non-technical maintenance object quality evaluation and change prediction connection.

Formula (12) describes generalized quality object model. Object ability parameter shows how its value, changing in time, affects object durability (T) and reliability (N), as two primary object ability state characteristics. Proposed parameter is complex number (the real part describes durability resource T and object material and technological features; the imaginary part describes reliability resource N and object features concerns human decisions (named „human factor“)).

$$Z_u = T - iN \quad (12)$$

where:

$Z_u = T + iN$ – generalized reliability-durability object model,

$$T = \int_{x_p}^{x_d} \sum_{x=1}^n x_{pt} \quad \text{– object durability reserve,}$$

x_{pt} – any diagnostic durability parameter,

x_p – initial value of diagnostic durability parameter,

x_d – acceptable value of diagnostic durability parameter.

$$N = \int_{x_p}^{x_d} \sum_{x=1}^n x_{pn} \quad \text{– object reliability reserve, reliability redundancy when object meet the planned before expectations (or changed during),}$$

x_{pn} – any diagnostic reliability parameter,

x_p – initial value of diagnostic reliability parameter,

x_d – acceptable value of diagnostic reliability parameter.

Therefore, maintenance factors, raw materials, environment, the pace and load of an object changes have influence on the real part (formula 12). Variability of human/operator competence, accepted maintenance strategy and maintenance/organizational procedures have influence on the imaginary part.

Changing object state during maintenance is natural, unavoidable process. The particular maintenance situation have only influence on dynamic changing state parameters (material and intellectual factors).

So, the object must be seen as: technical object, maintenance situation, human resources and relation between them determining the object dynamic changing state.

Durability resource depends on:

- parameters acceptable changes of length intervals (initial durability resource),
- completion of recovery processes;

whereas its rate of decrease depends on:

- possibility of prophylactic service implementation,
- object life for its worse than designer predict condition ,
- payloads, environmental and materials changes.

While reliability resource mainly depends on:

- initial reliability resource,
- completion of recovery processes,
- reliability redundancy.

Reliability parameter can be analyzed in two aspects:

- work reliability for specific conditions depends on impact resistance and object counteract damage ability,
- reliability to meet operators expectations (expectations increasing and decreasing for new and used object – meeting operators different use expectations analysis),

Reliability depends on:

- preservation of diagnostic parameters in acceptable limits,
- preservation of required parameter values within the existing limits identified by designer during modernization process,
- completion of different expectations configuration and cooperation with other objects tasks,
- keeping price competitiveness with other same class objects,
- safety,
- risk (safety loss, costs prediction, profitable recovery, modernization etc.).

Object which is considered as able to use needs to have specific level of reliability and durability resource, if not the object will be withdraw from use.

Reliability-durability selected individual models:

- $Z_u = T$ which means that $iN = 0$; it means that object durability resource was expended or object expectations has been changed that object has no capabilities to meet the expectations despite having durability resource or it means that object is durable in all spectrum of use T or there is no possibility to have an effect on its parameters and use (e.g. autonomous system after operator control disengagement like Pershing missile);
- $Z_u = iN$ which means that $T = 0$; it means that object meets the durability expectations in the whole range of life and its output is in line with the designer.

When $N = 0$ in maintenance reality, it could mean that human decisions have no influence on object state (object is no serviceable, changing life standards etc.) which means that that reliability–durability model transformed into durability model:

$$T = \int_{x_p}^{x_d} \sum_{x=1}^n x_{pt} \quad (13)$$

where:

T – object durability reserve as sum of durability reserves of object individual elements described by x_{pd} – diagnostic durability parameters in their ability limitations (from x_p to x_d),

x_{pt} – any diagnostic durability parameter,

x_d – acceptable value of diagnostic durability parameter,

x_p – initial value of diagnostic durability parameter.

$T=0$ in case, when all parameters reached a limiting state and there is no possibility to conduct renewing.

When $N=1$ it means that object is reliable (object meets the expectations independently from human decisions – usually in specified time – so is assumed to maintenance by service life with no predicted servicing). It means, that reliability-durability model transformed into reliability model:

$$N = \int_{x_p}^{x_d} \sum_{x=1}^n x_{pn} \quad (14)$$

where:

$$N = \int_{x_p}^{x_d} \sum_{x=1}^n x_{pn} \text{ or } N = \sum_{x=1}^n (x_d - x_p) \sum_{x=1}^n x_{pn} - \text{object reliability reserve as sum of reliability reserves of object individual elements described by } x_{pd} - \text{diagnostic reliability parameters in their ability limitations (from } x_p \text{ to } x_d),$$

x_{pn} – any diagnostic reliability parameter,
 x_d – acceptable value of diagnostic reliability parameter,
 x_p – initial value of diagnostic reliability parameter.

That kind of modeling is clear to understand especially when particular cases are considered, like: situations, when an object is in one-piece and is unrecoverable and its ability depends on keeping diagnostic parameters in borders limited by designer. Any further decisions are not considered. Therefore prediction of object ability takes into account the technical, organizational and management relations.

That kind of modeling allows to directly observe the changes of individual parameters on complex plane and durability and reliability optimization in view of any material and human parameter. It is important because, for the some parameters, change its value depends on load variation, which can be result of human factor or changes in the technologic or climate conditions. It is hard to determine which factor is the most important at the moment. However, we are able to continuously observe the changes if we consider individual decisions in general context. In that case use of complex numbers in maintenance changes process description, which do not lose technical and non-technical relations. What is more the description allows to observe and capture any maintenance relations. Single change of condition durability can be described as change results from adding ΔT and ΔN :

$$\Delta Z_u = \Delta T + i\Delta N \quad (15)$$

The sum of changes:

$$\sum \Delta Z_u = \sum \Delta T + i\sum \Delta N \quad (16)$$

Formula (12) after taking changes (16) into account is:

$$Z_u + \sum \Delta Z_u = T + \sum \Delta T + iN + \sum \Delta N \quad (17)$$

Therefore general parameter of the object ability Z_u taking changes into account for moment i is:

$$Z_{ui} = \frac{T + \sum \Delta T + iN + \sum \Delta N}{\sum \Delta Z_u} \quad (18)$$

2.4.1. Practical implication from (12) and (17) models

As a result of (12) i (17) models are very important, practical observations like:

- Two maintenance systems (or two maintenance states in the same system) are equal, when $\text{Re } z_i = \text{Re } z_j$ and $\text{Im } z_i = \text{Im } z_j$, or, when states concerning systems material parts are equal and at the same time states concerns elements come from human factor (decision-making) are equal.

Formula (12) allows:

- To evaluate and to predict, in generalized suitability indicator of the system analysis, the role of material part and human factor, and thereby if object maintenance system is equable (if we know what proportion of the real part and imaginary part should be for effective implementation of the maintenance process).
 - When we put two systems into one (two objects into one) we have clear view of system total rate, because new system or object addition could improve (deteriorate) the real part (material) and imaginary part of the rate as well. If we are interested in general profit, simple calculation of the profit or lost rate of the systems connection is possible. Moreover it gives us rate for the adequacy of the applied prevention evaluation to balance of the system, because if the imaginary part deteriorate increasing the real part will be pointless.
 - If the general parameter of the object ability Z_u combines in a relationship with transferring possibilities or probable corporation profit, the value of the parameter will present the potential of the corporation.
 - If we associate the imaginary part with corporation capability of market adaptation (intellectual capital) and the real part with new technologies and financial capital we can observe change of the potential and development of the corporation and its capability of taking on challenges in new markets, determining intellectual reserve to challenging of the new task or capital reserve to increase material production.
 - If we are capable to evaluate task (projects) needs by general parameter of the object ability Z_u then simple transformation of the rates in space⁸ ($C, +$) allows to analyze corporation ability to execute and searching the most effective ways of use corporation resources simulation (material and intellectual).

3. Summary

A proposed approach to modeling of object work range deterioration and especially to assessing the impact of properties change (as a result of work range deterioration) on task performance efficiency is a n attempt to include complex problem of many factors random influence which deteriorates object work range and their random influence on the quality of performed tasks. Adopting probabilistic tools/apparatus and fuzzy logic in modeling (at adopted model assumptions of an object) appears to be the right research direction when designing efficient and cost effective ways of solving problems of connecting variable factors with/of operation, maintenance, environment and

⁸ C - complex numbers space.

safety conditions in operational technical objects reality. It is assumed that models of the type allow for better approximation to operational reality and thereby better utilization of the object work range while maintaining the assumed level of their reliability/safety performance/effect achievement.

The problems presented in the paper do not exhaust the considered issue but only indicate the area of the planned by the authors scientific publications on this problem in the nearest time. Subsequent

articles will present detailed developments in proposed methods and show their applications for e.g. comparing the obtained results, determining the ranges of a given method use, as well as their implementation in database systems to provide support for object administrators/commanders/owners in the decision making process.

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