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Development of the Dependability and Quality Assessment Method for the Design of Wireless Devices

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***Abstract*—Automation of control methods of necessary requirements fulfilment or non-fulfilment while ensuring dependability and quality for wireless devices (WD) are necessary at design stages. However, this approach is not used in enterprises. Companies are limited only to expert assessment (non-automated external audit) and assessment of efficiency private criteria in the quality management system (QMS). The existing statistics of failures of radio engineering devices installed on unmanned automatic spacecraft indicates that there are shortcomings of ensuring the dependability and quality of the WD strategy. Therefore, in this paper, the method of dependability assessment of the WD considering the quality management system is proposed. The paper presents a mathematical model of dependability assessment of the WD considering not only the categories of the WD failures but also the private criteria contribution of the QMS functioning efficiency. Automation of the method is achieved by using the developed software.**

Keywords*—*reliability, quality management system, wireless device, unmanned automatic spacecraft.

I. INTRODUCTION

Failures Statistics of the wireless devices (WD), which are part of the unmanned automatic spacecraft (UAS), are given in the official open Internet source [1]. According to the data [1], there is a clear trend of increasing risk ratio of projects related to space services. It should be noted that the WD failures of the unmanned automatic spacecraft in most cases are associated with failures in electronics [1]-[3] during operation. The rapid growth of the WD functional and hardware complexity which are part of the UAS and insufficient dependability of the radio devices are accompanied by significant shortcomings that serve as reasons for space devices failures. However, workability of the UAS majority that operating for less than 15 years and more than 15 years is ensured due to the significant hardware redundancy which leads to a large number of shortcomings such as the UAS excess weight, the high cost, the complexity of simulation modelling in assessing the dependability indicators. Taken together, all the consequences lead to difficulties in ensuring the cost-effectiveness in creating the long-term geostationary orbit (GSO) UAS with an active life up to 15 years for providing space communications services.

Therefore, there is a complex problem of ensuring dependability not only of the WD but also of the UAS in general, which is caused by the following key factors [3]:

- Hardware complexity.
- Harsh and unfavorable operating conditions at GSO.
- Extremely high level of the dependability requirements, determined by the high cost of the projects (the cost-effectiveness in creating the long-term GSO UAS with an active life up to 15 years).
- Singularity and uniqueness of development and production processes.

To effectively ensure the UAS dependability it is necessary to find out the root causes of low dependability, which, in most cases, are associated with the radio technical devices failures [4].

Failures that occur during operation can be fatal, partial or parried (faults). The UAS wireless devices are more often characterized by a fatal failure, which leads to an accident and emergency situations.

By 2010, the Reliability Information Analysis Center (RIAC) published data on the distribution of the general civil WD failure categories, which are treated differently by several sources (Fig. 1). However, information about special-purpose WD failures is not published in free access, so it can be assumed with high probability that an identical distribution of failure categories is observed during operation of the military and space WD [4]. The description of the failure categories is presented in the standard [5]. Also, the failure categories are discussed in detail by the authors in the source [6] and interpreted in a different way.

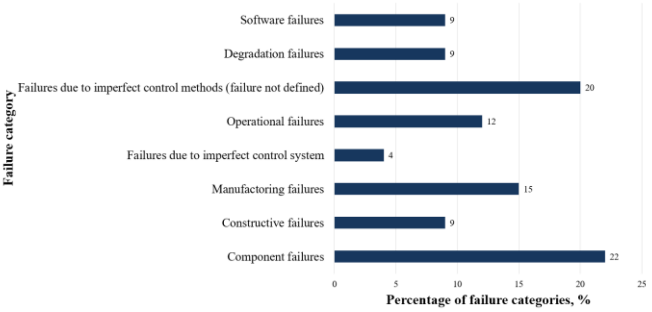

Fig. 1. The WD failure categories distribution according to RIAC Reliability Research Center data according to American dependability reference book RIAC-HDBK-217Plus [7].

Figure 1 shows that in 20% of the failure cases it was not possible to establish a specific category. Therefore, it is possible to make an assumption that indicates the non-fulfilment the necessary measures while ensuring the dependability and quality of the WD during the life cycle processes.

A high percentage of component parts failures such as electric radio devices (ERD) is also unacceptable, which

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aggravates the problem of ERD dependability. This is because the WD developers are compelled to use old reference data of 1980-1990 for estimation the ERD dependability which does not correspond to modern manufacturing technologies and do not submit to the new mathematical models of the operational intensity of failures.

The current situation with the failures categories is largely explained by the incorrect functioning of the Quality Management System (QMS) at the enterprises while producing the UAS WD at the design stage [3]. That is why toughening and automation of measures control is necessary for the numerical estimation of life cycle processes during the WD development according to the technical requirement (TR).

Therefore, the purpose of this work is to increase the credibility of the WD dependability numerical evaluation considering the efficiency of QMS functioning and external influencing factors (EIF).

II. MAIN EXTERNAL INFLUENCING FACTORS

During the development of unmanned automatic spacecraft the requirements of high dependability with minimum dimensions, mass and cost are imposed and the active life is from 0.5 to 25 years depending on the type and mass [8].

The UAS are exposed to EIF during their operation:

- The mechanical effects (ground operation, launch and launch into space, separation of steps and the UAS separation, orbit correction).
- The thermal effects.
- The earth's climatic effects.
- The radiation effects (electrons and protons of natural and artificial origin).

The UAS are exposed to additional factors when using space equipment in non-hermetic containers:

- The vacuum exposure.
- Exposure to heavy charged particles, causing thyristor effects as well as loss of information on flash memory.
- Inherent atmosphere exposure.
- Electrostatic discharge exposure.
- The manifestation of the electromagnetic compatibility effects of on-board systems, in particular, wireless devices.
- The ERD degradation during long periods of active life.

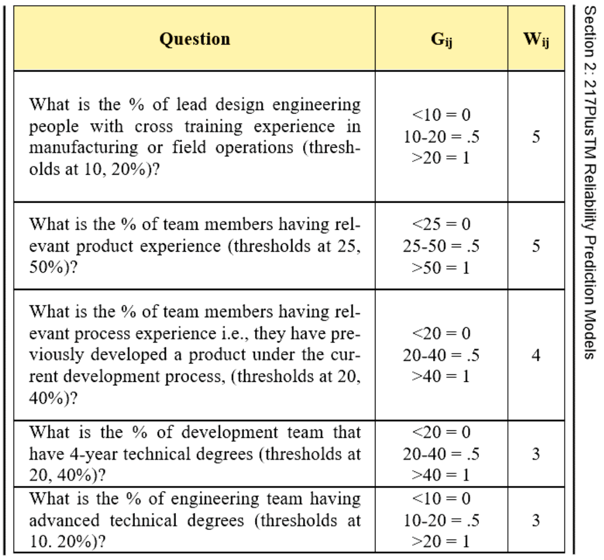
The number of the ERD in modern UAS is in the range from 120 thousand to 200 thousand according to [3]. They are connected to each other by redundancy schemes and without them. For example, the Russian UAS "Yamal-401" 2014 contains about 150 thousand and more WD pieces of various classes. Ensuring reliable and long-term operation of the WD which contains a huge number of ERD and performed in non-hermetic execution, is a very difficult task in the space conditions. This task requires considerable intellectual and financial expenses - and all this is possible only when the enterprise's QMS functions correctly.

III. FEATURES OF FORECASTING AND DEPENDABILITY CONFIRMATION

The dependability confirmation by the calculation methods has the same problems as in the forecasting: the absence of modern adequate dependability estimation methods of complex space systems with a long-term life time, the absence of reliable initial data for calculations (reference data on the ERD λ-characteristics). In particular, the main problem is a reliable assessment of the "production quality factor" K_A.

Russian and American approaches to the assessment of λ-characteristics considering the K_A of the UAS WD are given in the source [9]-[11]. The disadvantage of the Russian approaches is that the K_A values are given in an integral estimate [12], and also does not take into account the constant change of measures aimed at quality improvement given in the standards [13]-[15] and the source [16]. However, as it was mentioned earlier, the failure statistics contained in the sources [1]-[3] shows that these approaches do not achieve the target level of dependability during developing the UAS WD.

American approach also has several shortcomings. First, the evaluation mathematical model of "production quality factor" K_A, takes into account several coefficients that do not belong to the UAS WD - a coefficient of Π_{IM}, because it is characterized by the active lifetime, as well as the Π_G coefficient because a Π_S coefficient is already participates in the model (dependability management system is part of the QMS) according to the source [7]. Secondly, there are no coefficients necessary for accounting at all, for example, the coefficient that takes into account the disadvantages of circuit solutions, such failures are typical for the UAS [3]. The analysis of the questionnaire (an example of the questionnaire for the Π_D coefficient is presented in Figure 2) allows to draw the following conclusion that the questions for each of the used coefficients have a chaotic order, there is no indication of belonging to the normative and technical documentation (NTD) and there is no internal classification of the questions.



Section 2: 217PlusTM Reliability Prediction Models

Question	G_{ij}	W_{ij}
What is the % of lead design engineering people with cross training experience in manufacturing or field operations (thresholds at 10, 20%)?	<10 = 0 10-20 = .5 >20 = 1	5
What is the % of team members having relevant product experience (thresholds at 25, 50%)?	<25 = 0 25-50 = .5 >50 = 1	5
What is the % of team members having relevant process experience i.e., they have previously developed a product under the current development process, (thresholds at 20, 40%)?	<20 = 0 20-40 = .5 >40 = 1	4
What is the % of development team that have 4-year technical degrees (thresholds at 20, 40%)?	<20 = 0 20-40 = .5 >40 = 1	3
What is the % of engineering team having advanced technical degrees (thresholds at 10. 20%)?	<10 = 0 10-20 = .5 >20 = 1	3

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Fig. 2. Part of the questionnaire to assess the Π_D coefficient according to the source [7].

However, the study of each question from the questionnaire [7] showed that it is possible to classify them according to the life cycle (LC) processes of systems based on the standard ISO/IEC/IEEE 15288:2015 [17]. The LC processes are divided into 4 types:

- The contracting processes.
- The organisational procedures.
- The project processes.
- The technical procedures.

Each type of processes is divided into subtypes (Fig. 3) with a necessary actions description [17].

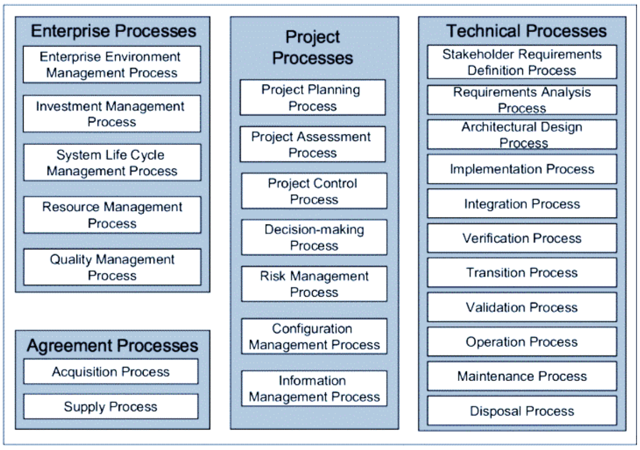

Fig. 3. Life cycle processes of the system according to the source [17].

Each LC process goes through one of the stages (the period within the LC system, which refers to the state of the system description or directly to the system):

- Intention (concept).
- Development.
- Production.
- Application (operation).
- Application support (maintenance).
- Termination of use and write-off (disposal).

On this basis, the questions concerning those mathematical model K_A coefficients [7] that imply expert evaluation were investigated. It was found out that most of the questions are directly related to the LC systems processes. The rest of the questions either related to the staff or the product (focus of questions). The direction of the questions is formed on the basis of ontological research, which is described in work [10]. The above-mentioned is confirmed by the data presented in Table 1.

TABLE I. PERCENTAGE DISTIBUTION OF QUESTION ORIENTATIONS IN HANDBOOK QUESTIONNAIRES [7]

№	**Coefficient**	**Question orientations (percentage distribution), %**		
		Process	**Staff**	**Product**
1	Π_P	95	–	5
2	Π_D	76	8	16
3	Π_M	92	7	1
4	Π_S	85	13	2
5	Π_I	91	9	–
6	Π_N	77	11	2
7	Π_W	97	2	1

Each of the questions refers to a specific stage. All the LC processes and stages in the reference book [7] are covered. Despite this, it is possible to obtain only the actual numerical value of this coefficient having only a mathematical expression to estimate K_A, but it will not be possible to examine it in detail, so it will not be possible to find out the reason for the degradation of this coefficient value (at least at the level of questions' orientation).

IV. PROPOSED METHOD FOR WD DEPENDABILITY ASSESMENT

Shortcomings described in the previous sections related to the reliable assessment of the “quality factor of production” K_A and λ-characteristics of the UAS WD is proposed to eliminate using an improved mathematical model (1). This model considering the updated coefficient K_A "production quality factor", based on the categories of failures and their percentage distribution, as well as ontological research of issues. Also the mathematical model (1) considering the QMS private criteria effectiveness based on the quality management principles [13] and is able to considering the specified intensity of the ERD failures, confirmed by the results of additional tests.

$$\lambda_{WD} = \frac{K_A^*}{\sum_j \frac{V_j}{100} \cdot K_j} \cdot \left(\sum_{n=1}^{N} \lambda_{ERDn} \cdot K_{AD} \right) \cdot K_{QMS}\,, \tag{1}$$

where K_A^* is a production quality factor taking values according to the reference [12]; N is the ERD total quantity; λ_{ERD} is the ERD failures intensity; K_{AD} is the coefficient of the ERD (takes values from "0" to "1") additional tests (accelerated); R_{QMS} is a coefficient characterizing the QMS performance based on private criteria [9]; V_j is a failure rate for the j-fault category (Fig. 1); K_j is a coefficient characterizing the category of failure (Fig. 1) and estimated according to expressions (2-6):

$$C_{mnkl} = \frac{\sum_{i=1}^{Q_{\max}} \gamma_{imnkl} \cdot G_{imnkl}}{\sum_{i=1}^{Q_{\max}} G_{imnkl}}\,, \tag{2}$$

where C_{mnkl} is a coefficient characterizing m classification of questions i for each of the directions n included in sections k, which are included in the NTD l; Q_{max} is the maximum number of questions i for each classification m; C_{imnkl} is the weighting coefficient of the i question (requirement); γ_{imnkl} is the numerical value of the question depending on the answer (range of values from 0 to 1);

$$F_{nkl} = \frac{\sum_{m=1}^{C_{\max}} C_{mnkl} \cdot GC_{mnkl}}{\sum_{m=1}^{C_{\max}} GC_{mnkl}}, \qquad (3)$$

where F_{nkl} is a coefficient characterizing the n orientation of questions i for each section k included in the NTD l; C_{max} is the maximum number of classifications m for each direction n; GC_{mnk} is a weight coefficient (significance) of each classification m;

$$R_{kl} = \frac{\sum_{n=1}^{F_{\max}} F_{nkl} \cdot GF_{nkl}}{\sum_{n=1}^{F_{\max}} GF_{nkl}}, \qquad (4)$$

where R_{kl} is a coefficient characterizing the k orientation of questions i for each section k included in the NTD l; F_{max} is the maximum number of classifications n for each direction k; GF_{nkl} is a weight coefficient (significance) of each classification n;

$$N_{l} = \frac{\sum_{k=1}^{R_{\max}} R_{kl} \cdot GR_{kl}}{\sum_{k=1}^{R_{\max}} GR_{kl}}, \qquad (5)$$

where N_l is a coefficient characterizing l in the NTD which include questions i; R_{max} is the maximum number of classifications k for each NTD l; GR_{kl} is a weight coefficient (significance) of each classification k;

$$K_{j} = \frac{\sum_{l=1}^{N_{\max}} N_{l} \cdot GN_{l}}{\sum_{l=1}^{N_{\max}} GN_{l}}, \qquad (6)$$

where N_{max} is maximum number of l in the NTD classified as failures j; GN_l is a weight coefficient (significance) of each l NTD.

The determination of the requirement weights in the NTD is done by experts using unclear logic. The point is that according to the standard ISO 9001-2015 [13] the quality of the product must be measurable. However, besides the requirements, there are many other factors that influence the result. On this basis, it is necessary to assess the quality of documents with requirements (NTD) and models of requirements. The main "quality criteria" are ranking (importance), complexity, correctness, unambiguity, consistency, verifiability, comprehensibility. Therefore, according to these criteria, it is possible to conduct the operation to identify the weight coefficients of each NTD requirement. Then "quality criteria" is the name of a linguistic variable, which is formed by the basic term sets which contains three fuzzy variables: "low", "medium", "high". An example of the membership function *MF(x)* for the criterion "complexity" is shown in Figure 4.

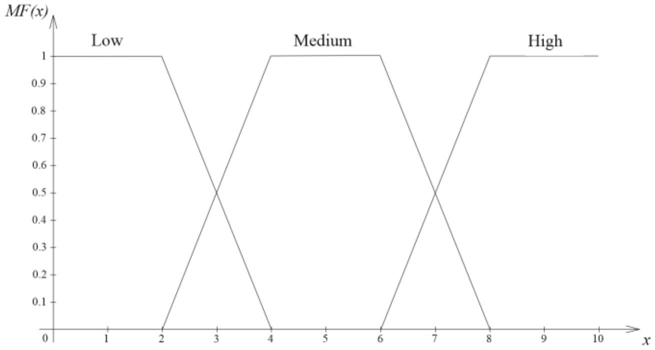

Fig. 4. Membership function for a linguistic variable "complexity".

The area of reasoning for the linguistic variable "complexity" is given in the form $x = [a; d]$ for $a = 0$, $d = 10$.

V. AUTOMATION OF WD DEPENDABILITY ASSESMENT METHOD

The following software implementation is proposed in the form of 3 blocks on the basis of the methodology given in the source [11] (1 - filling the database with requirements according to the NTD; 2 - determination of weight coefficients of requirements by experts; 3 - survey audit: internal and external). Let's review each block separately.

The database is filled in according to the ontological structure [10] of the questionnaire to assess the coefficients characterizing the failure category (Fig. 1).

The weight coefficient determination of each requirement by the user in the proposed software is shown in Figure 5.


Criteria

Ranging 10

Complexity 7

Correctness 10

Unambiguity 10

Consistency 8

Verifiability 10

Comprehensibility 8

Weight coefficient 8,2

Fig. 5. Determining the requirement of the weight coefficient in the developed software.

The questionnaire is carried out in the form of answers to the questions (verification of compliance with the requirements, according to the NTD) that is similar to [7]. An example of the numerical evaluation of the coefficients included in the K_A model [10] at the failure category level is shown in Figure 6.

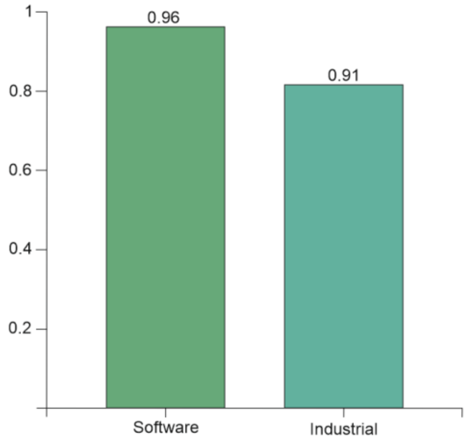

Fig. 6. Bar chart, showing the result of the numerical estimation of coefficients in the developed software on the failure categories level.

It is also possible to give an example of the numerical estimation of the coefficients included in the K_A model [10] at the section level in a particular NTD (Fig. 7).

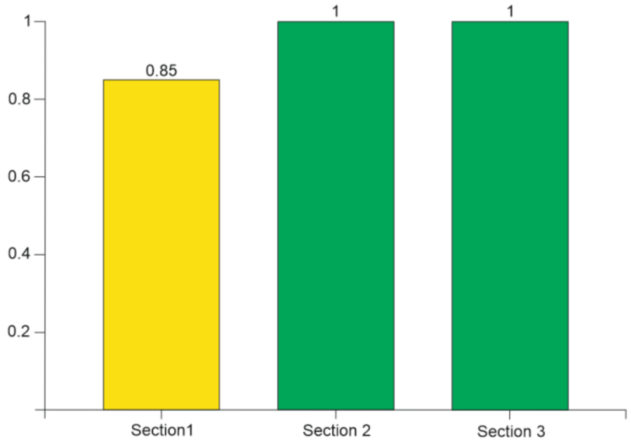

Fig. 7. Bar chart showing the result of the numerical estimation of coefficients in the developed software at the section level in a particular State Standard (conditional).

Thus, the results of the internal and external audits are clearly and conveniently presented according to a structured approach to K_A evaluation.

The other coefficients included in the model (1) are entered into the software fields as numerical values.

VI. CONCLUSION

The developed method will allow estimate an achievable level of dependability indicators of the UAS WD not only based on their λ-characteristics but also considering external influencing factors, the quality management system efficiency of functioning and the specified "production quality factor". The final one is achieved due to the developed software with a detailed analysis of the normative and technical documentation requirements of the compliance control.

The application of the “production quality factor”, obtained by taking into account the influence of the QMS, will increase the accuracy of the UAS WD reliability characteristics calculations at the design stage. And the proposed method will increase the credibility of the target level achievement assessment of the UAS WD dependability indicators. This method will rid the organizations from the procedure of additional tests. This will increase projects profitability in the sphere of space communication services provision.

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