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FORMALIZATION OF THE INFORMATION ON THE CONDITION OF THE ELECTRIC POWER SYSTEM IN RISK-BASED MAINTENANCE STRATEGY

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Gostyunin Yuriy Anatolyevich, Astrakhan State Technical University, 16 Tatishchev St., Astrakhan, 414056, Russian Federation,

post-graduate student, e-mail: gostyuninyua@gmail.com

Stanishevskaya Alina Vladimirovna, Astrakhan State Technical University, 16 Tatishchev St., Astrakhan, 414056, Russian Federation,

graduate student, e-mail: a.stanishevskaia@gmail.com

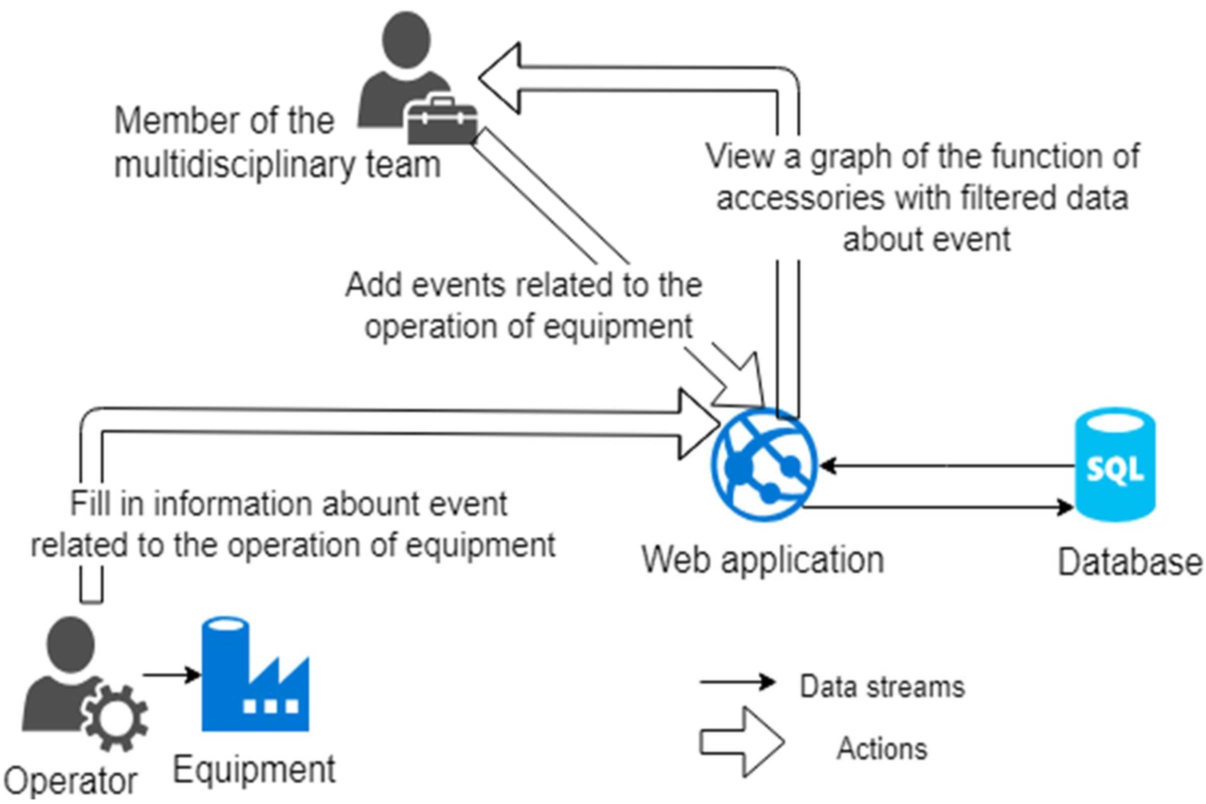
Azhmukhamedov Iskandar Maratovich, Astrakhan State University, 20a Tatishchev St., Astrakhan, 414056, Russian Federation,

Doct. Sci. (Engineering), Professor, e-mail: iskander_agm@mail.ru

Modern electric power systems belong to the category of complex power systems, the reliable and safe functioning of which requires a solid assessment of their technical condition. Maintenance of power systems is often implemented on the basis of risk assessment. At the same time, it is difficult to collect basic data, which are mostly of verbal (non-numeric) character. Based on the abovementioned, the article considers the problem of using expert assessments in a risk-oriented maintenance strategy applied to the electric power systems operation process. The paper provides an example of the formalization of information on malfunction occurrence frequency in one of electric power system objects. The article describes a developed software product, which automates the formalization process of fuzzy expert information obtained for risk assessment.

Key words: equipment maintenance, linguistic variable, fuzzy parameter value, term set, membership function, expert assessment, risk-based maintenance strategy

Graphical annotation (Графическая аннотация)



ФОРМАЛИЗАЦИЯ СВЕДЕНИЙ О СОСТОЯНИИ ЭЛЕКТРОЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ В РИСК-ОРИЕНТИРОВАННОЙ СТРАТЕГИИ ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ

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Гостюнин Юрий Анатольевич, Астраханский государственный технический университет, 414056, Российская Федерация, г. Астрахань, ул. Татищева, 16,
аспирант, e-mail: gostyuninyua@gmail.com

Станишевская Алина Владимировна, Астраханский государственный технический университет, 414056, Российская Федерация, г. Астрахань, ул. Татищева, 16,
магистрант,e-mail: a.stanishevskaia@gmail.com

Ажмухамедов Искандар Маратович, Астраханский государственный университет, 414056, Российская Федерация, г. Астрахань, ул. Татищева, 20а,
доктор технических наук, профессор, e-mail: iskander_agm@mail.ru

Современные электроэнергетические системы относятся к разряду сложных энергетических систем, надежное и безопасное функционирование которых требует достоверной оценки их технического состояния. Техническое обслуживание электроэнергетических систем чаще всего реализуется на основе оценки рисков. При этом возникают трудности со сбором исходных данных, которые в основном носят вербальный (нечисловой) характер. Исходя из этого, в статье рассмотрена проблема использования экспертных оценок в риск-ориентированной стратегии технического обслуживания применительно к процессу эксплуатации электроэнергетических систем. Приведен пример формализации сведений о частоте возникновения неисправностей на одном из объектов электроэнергетической системы. Описан разработанный программный продукт, позволяющий автоматизировать процесс формализации нечеткой экспертной информации, полученной для оценки рисков.

Ключевые слова: обслуживание оборудования, лингвистическая переменная, нечеткое значение параметра, терм-множество, функция принадлежности, экспертная оценка, риск-ориентированная система технического обслуживания

Introduction. Modern electric power systems (EPS) and their constituent facilities (power plants, electrical networks) are classified as complex technical systems (CTS). Reliable and safe operation of an EPS is feasible only when prompt and reliable assessment of the technical condition of the equipment, its operational reliability and reasonable and adequate decisions on its further operation are provided [3].

The operation of an EPS is a complex process that is subject to numerous and varied risks due to the influence of various random factors and the presence of many uncertainties in all aspects of the undertaking. In summary, the risks characterize the probability and possible damage during the operation of an EPS [9]. The nature of the damage may be different and can be expressed not only in the form of economic values, but in a form other than that, as well. During the operation of an EPS, risk management strategies based on RBM (Risk-Based Maintenance) are increasingly used. However, the application of such a strategy leads to considerable difficulties at the stage of collecting initial data, which are mainly of verbal (non-numeric) nature [4].

Based on this, the purpose of this work was the development of a methodology for formalizing basic information about the status of an EPS for assessing their operation risks and the development of appropriate software to implement the proposed methodology.

Materials and methods. As the initial data for risk assessment are of a verbal (non-numeric) nature, it is advisable to use methods of the fuzzy sets theory in conjunction with the methods of probability theory and mathematical statistics for their formalization and further consideration when making management decisions.

Results and Discussion. The RBM strategy is based on the RBI (Risk Inspection) methodology, which is described in the standards of the American Petroleum Institute (API), the American Community of Mechanical Engineers (ASME), the independent classification and certification society Det Norske Veritas [7,8]. According to this methodology, the probability of equipment failure and the consequences of this failure are estimated, the magnitude of the risk is defined as their multiplication:

$$R = DP, \qquad (1)$$

in which R – risk value; D – value, characterizing the severity of the undesirable event. It can be described by specific parameters (consequences of failure, damage). The range of parameters, used in this process, can be quite wide – from economic values to human victims; P is the probability of a possible equipment failure.

According to the RIMAP (Risk based Inspection and Maintenance Procedures), to determine the D and P values in formula (1), different data sources have to be used. One can use equipment statistics and failures, technical conditions and consequences of failures, simulation results, expert estimates as information sources [5].

In practice, the collection of input data to determine the desired values of D and P is a rather time-consuming task. Usually if there are models, suitable for the analysis of failures and their consequences, they describe only the most critical elements. Moreover, the models that are created quickly lose their relevance due to the introduction of new production technologies.

Statistical data is another important source of information, which may be used to determine the probability of equipment failure and the consequences of failure. Availability of well-structured statistical information on operation process and equipment failures, facilitates the analysis carried out in accordance with the RIMAP procedure. It is possible to use statistics on a similar object, taking into account a possible error, caused by a lack of statistical information about the object [6].

However, for practical consideration, only an approach to statistical information analyzing is required [2].

A multidisciplinary team, specialists, who should be qualified to inspect it or another system, can give an expert assessment of the power system condition.

The group of experts should make a collective decision, that is why it is possible to use in their work the methods of collective expert assessment: the Delphi method, the brainstorming method, the court method, the round table etc.

The multidisciplinary team should be able to interact with the staff that services the equipment. A person, who directly handles maintenance of technical objects, can provide valuable information about equipment in the subjective form. It is often difficult for the interviewed employee to evaluate an object numerically based on a certain criterion. Usually experts use their native language words when verbally describing many characteristics of the objects. Thus, the source information contains significant subjective uncertainty. For this reason, it is advisable to use the apparatus of the fuzzy sets theory to formalize the information, received from maintenance staff.

When a person perceives information, he or she does not use concrete numbers, but translates it into his or her concepts - the values of a linguistic variable. Each value of the linguistic variable is described by the membership function, which is unique for every person. Suppose when an employee observes the equipment or system for some time, he fixes his attention n times on the presence or absence of fact A. An event consisting of n fact existence checks A is called an evaluative. Suppose that the fact A has occurred in the k checks. Then, the operator registers the frequency $p = k / n$ of the occurrence of fact A and evaluates it using with the words “often”, “rarely” etc.

Assume that at the stage of input data collecting, the multidisciplinary team suggests that the operator evaluate the occurrence frequency of a maintained equipment malfunction in terms of a linguistic variable. It is necessary to design an individual membership function of linguistic terms for the numerical interpretation of information from the operator. For this purpose, it is possible to use a method that is based on statistical data processing.

Consider the following example.

The table 1 presents an estimate of the equipment malfunction frequency in terms of the linguistic variable for a particular operator of the EPS object, collected prior to the start of the multidisciplinary group work. It is necessary to place the linguistic variable values: “very rarely”, “rarely”, “not rarely, not often”, “often”, “very often” on the universal scale [0,1]. As an example, let us divide the time interval into 20 segments, for which statistics was collected, that characterize how often a person uses these words to express his or her evaluations.

Table 1 – Estimation of the equipment malfunction frequency in terms of linguistic variable

Value	Time interval (segment)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Very rarely	3	7	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Rarely	0	0	1	0	4	1	6	4	1	0	0	0	0	0	0	0	0	0	0	0
Not rarely, not often	0	0	0	0	0	0	0	2	2	5	7	0	0	0	0	0	0	0	0	0
Often	0	0	0	0	0	0	0	0	0	0	3	8	0	7	5	2	3	0	0	0
Very often	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	7	5	2

Using the properties of the membership function, we must pre-process the data in Table 1 in such a way as to reduce the distortions, introduced by the experiment. The natural properties of the membership functions are the presence of one maximum and smooth fading to zero. For statistical data processing, we can use the so-called hint matrix. Firstly, it is necessary to remove obviously erroneous elements from table 1 (for example, the element “very rarely” in column 18). The removal criterion is the presence of several zeros in the string around this element [1].

Elements of the hint matrix are calculated by the formula:

$$k_j = \sum_{i=1}^{5} b_{ij}, j = 1 \dots 20, \tag{2}$$

in which k_j – element of the matrix, j – number of the column (time interval), i – number of the row (value).

The hint matrix is a string ||3 7 4 0 5 1 6 6 3 5 10 8 0 7 6 4 9 7 5 2||. In the row of table 1, we must select the maximum element: $k_{max} = \max k_j$ and then all the elements are converted by the formula:

$$c_{ij} = \frac{b_{ij} k_{max}}{k_j}, \; i = 1 \dots 5, \; j = 1 \dots 20, \tag{3}$$

in which c_{ij} – transformed element of the matrix

For columns, where $k_j = 0$, linear approximation is applied:

$$c_{ij} = \frac{c_{ij-1}+c_{ij+1}}{2},\ i = 1 \dots 5,\ j = 1 \dots 20. \tag{4}$$

It is necessary to find the maximum elements in the rows of table 1 to build membership functions: $c_{i\,max} = \max c_{ij},\ i = 1 \dots 5,\ j = 1 \dots 20$. The membership function is calculated by the formula:

$$\mu_{ij} = \frac{c_{ij}}{c_{i\,max}}. \tag{5}$$

There are the calculated values of the membership functions in a table 2. After approximation, this data may be presented in graphical form as the membership function (fig. 1).

Table 2 – Values of the membership function

μ_i	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
μ_1	1	1	0.75	0.47	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
μ_2	0	0	0.25	0.52	0.8	1	1	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0
μ_3	0	0	0	0	0	0	0	0.33	0.67	1	0.7	0	0	0	0	0	0	0	0	0
μ_4	0	0	0	0	0	0	0	0	0	0	0.3	1	1	1	0.83	0.5	0.33	0	0	0
μ_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.5	0.55	1	1	1

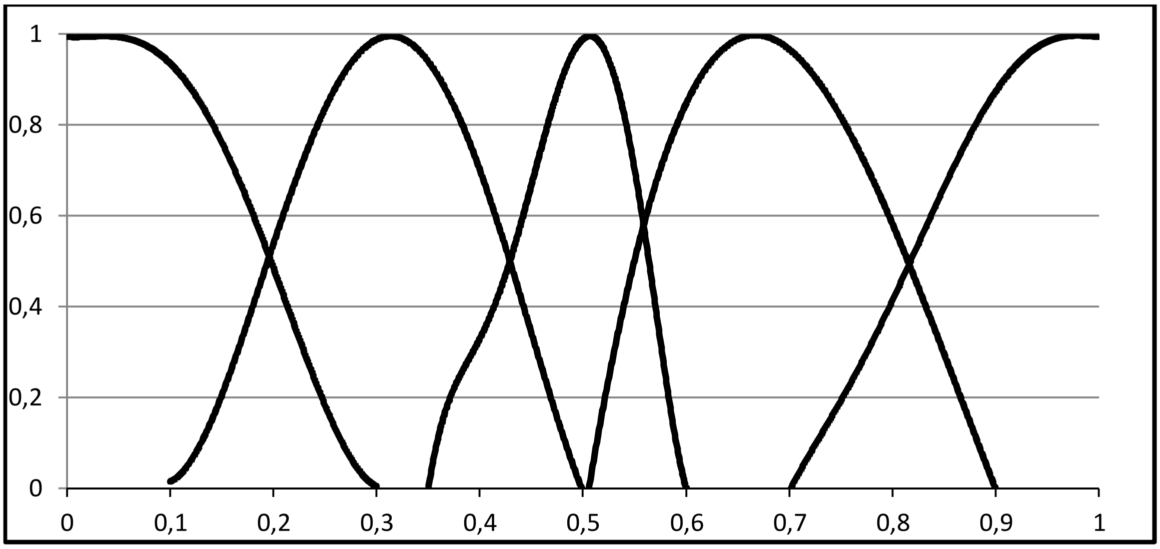


Figure 1 – Membership functions of linguistic variable values

As members of a multidisciplinary team and operators can be geographically located at the considerable distance from each other, a web application has been developed to make their interaction more comfortable. This enable all users to have access to the system, regardless of their location. The web application also allows users to receive all updates in the system instantly, without the need for further actions by users.

The application was developed in C# programming language with the use of Visual Studio 2017. Frontend was developed using HTML, CSS, Bootstrap, JQuery. MS SQL Server 2017 is used as a database.

The system must provide two types of users:

- Member of a multidisciplinary team;
- Equipment service operator.

A member of a multidisciplinary team has the following functionality:

- manage events related to the operation equipment;
- manage users;
- view the membership function graph.

The operator in charge of the equipment maintenance can enter data on the frequency of the event, related to the maintenance of the equipment, for the further analysis by members of the multidisciplinary group.

The Use-Case diagram is shown in Figure 2.

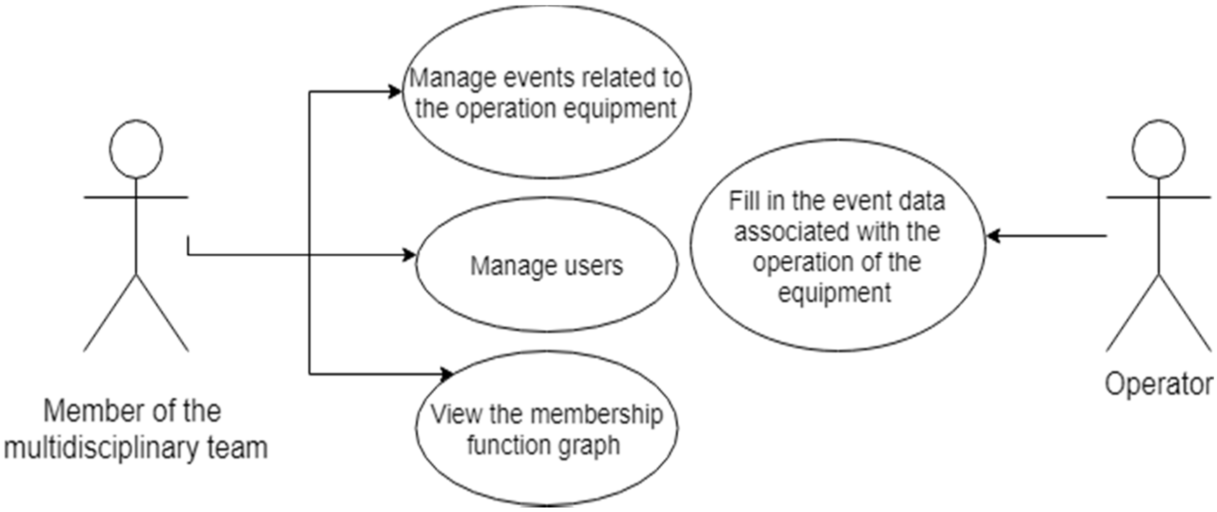


Figure 2 – The Use-Case diagram

When the user logs in for the first time, he or she have to authorize. There is no possibility to register in system, because the system is closed and all users are created by the members of the multidisciplinary group.

The authorization form is shown on the Figure 3.

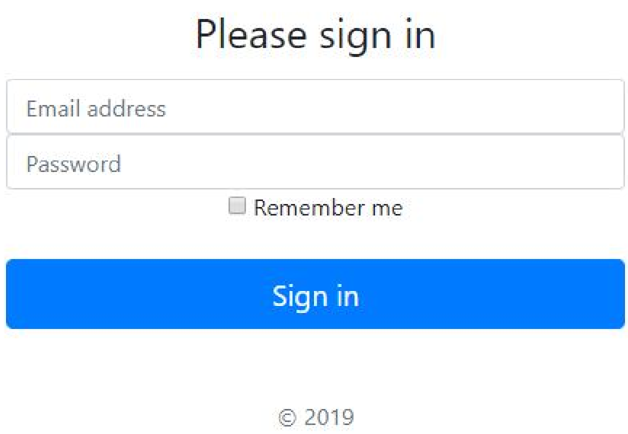


Figure 3 – The authorization form

After a successful authorization, a member of the multidisciplinary group in the Events section can create, edit and delete events, characterizing the power system condition (figure 4).

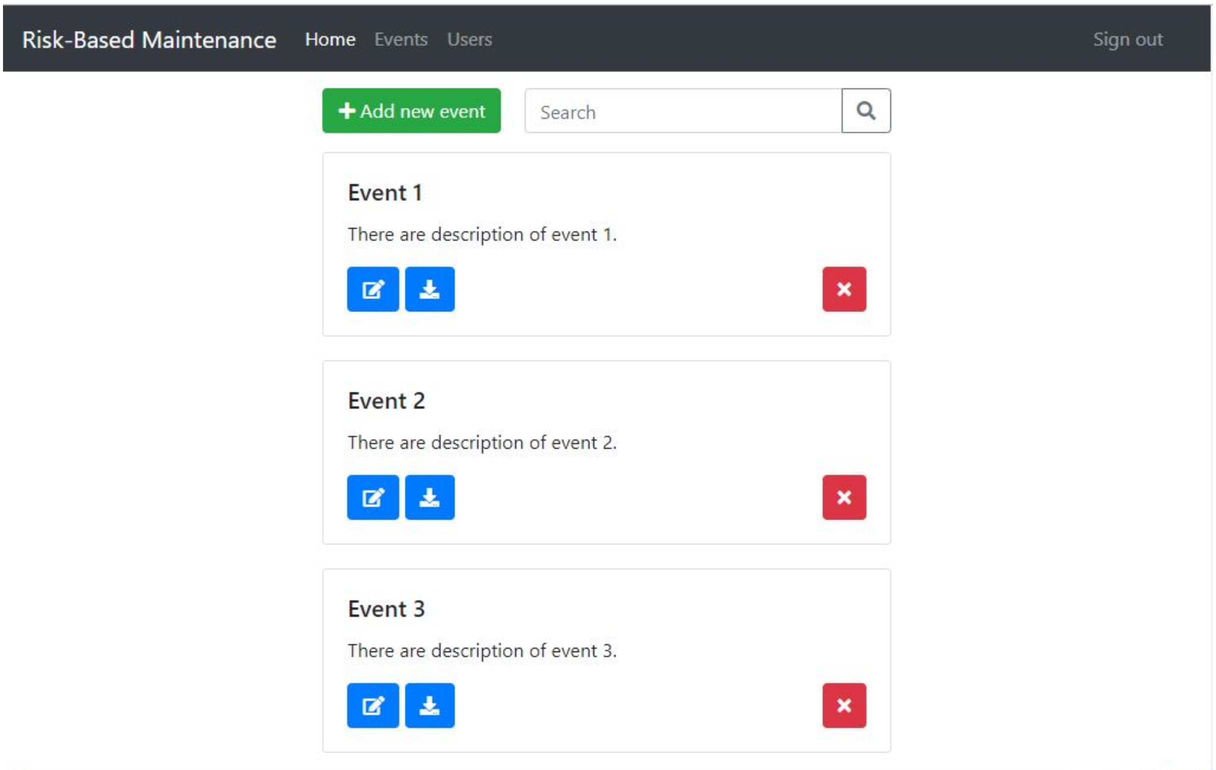
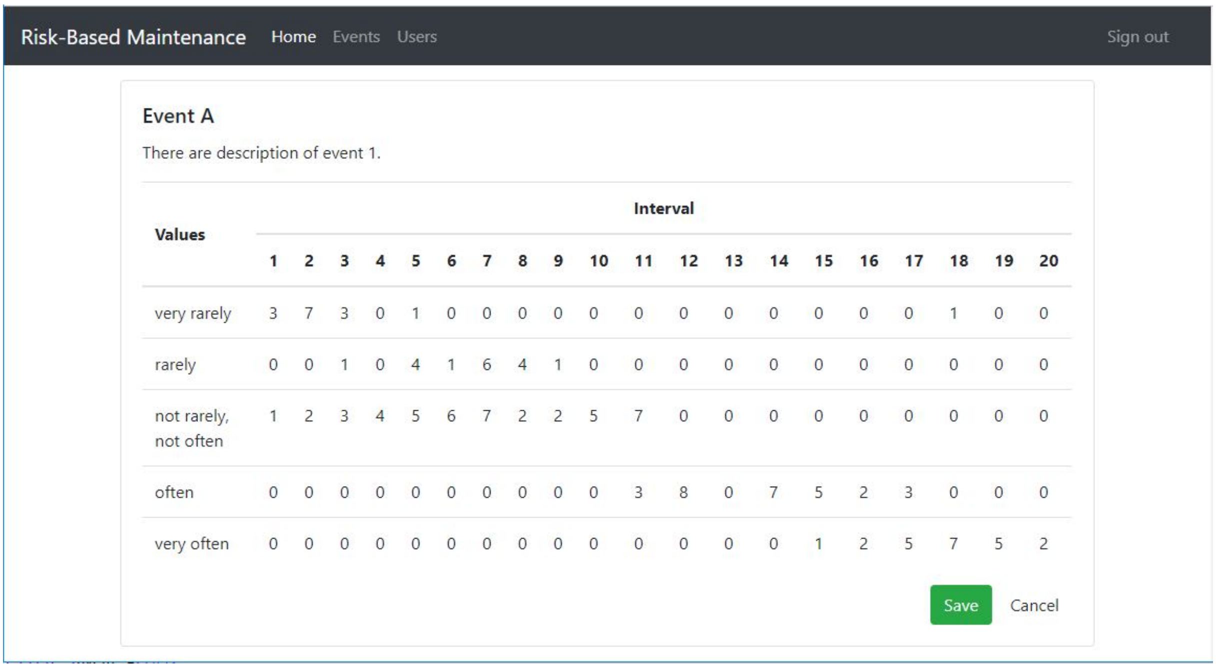


Figure 4 – Event management

The operator has to fill in the information about the occurrence frequency of an event, associated with the equipment operation (figure 5).



Values	Interval																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
very rarely	3	7	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
rarely	0	0	1	0	4	1	6	4	1	0	0	0	0	0	0	0	0	0	0	0
not rarely, not often	1	2	3	4	5	6	7	2	2	5	7	0	0	0	0	0	0	0	0	0
often	0	0	0	0	0	0	0	0	0	0	3	8	0	7	5	2	3	0	0	0
very often	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	7	5	2

Figure 5 – Information on the frequency of events, related to equipment maintenance

After processing the data, entered by the operator, the members of the multidisciplinary group get the processed results, presented as a membership function (Figure 1).

Conclusion. Thus, the paper proposes a methodology and software that implements it, which allows to formalize information about the current condition of the equipment. The developed web application enables users to report on the occurrence frequency of events related to the equipment maintenance at long distances and not to be dependent on the location of operators and multidisciplinary team members.

The data provided by the program helps the expert team understand the actual configuration and operating conditions of equipment operation, to assess the effectiveness of inspection and maintenance programs, to identify details of problems and possible failures.

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