SCIENCE AND TECHNOLOGY

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REMARKS ABOUT MODELLING OF MAINTENANCE PROCESSES WITH THE USE OF SCENARIO TECHNIQUES

UWAGI O MODELOWANIU PROCESÓW EKSPLOATACYJNYCH Z WYKORZYSTANIEM TECHNIK SCENARIUSZOWYCH*

This article aims at presenting the results of research use of modelling of exploitation processes in practical applications (industrial). Firstly, there has been made an identification and of solutions in this area, particular attention was paid equally to the problems associated with processes modelling in the context of wider organizational and technical approach. Basing on the performed studies, of both basic (theoretical) and industrial character, the research problem has been defined. It concentrates on the difficulties of using exploitation process models in relation to the maintenance organization in an industrial enterprise, because of their "flat" nature. Based on the developed research problem, there has been proposed a way of its solution by applying scenario techniques. Secondly, following a review of the state of knowledge (literature) in the context of exploitation scenario building, there has been prepared and presented a detailed research procedure, that will result in the development of methodology for creation of exploitation scenarios, including the way of their use in practice. The article is funded by National Science Centre in Poland under the project no. 5636/B/T02/2011/40 titled: "The use of scenario methods in exploitation processes modelling".

Keywords: *exploitation, maintenance, maintenance scenarios, exploitation processes, modelling.*

Celem artykułu jest zaprezentowanie wyników przeprowadzonych badań w zakresie sposobów wykorzystania metod modelowania procesów eksploatacyjnych w zastosowaniach praktycznych (przemysłowych). W pierwszej kolejności dokonano identyfikacji i klasyfikacji stosowanych w tym zakresie rozwiązań, zwrócono przy tym uwagę na problemy związane z modelowaniem procesów w aspekcie szerszego ujęcia organizacyjno-technicznego. W oparciu o przeprowadzone badania, które miały charakter zarówno podstawowy (teoretyczny), jak i przemysłowy, sformułowano problem badawczy. Jego istota sprowadza się do trudności wykorzystania modeli procesów eksploatacji w odniesieniu do funkcjonujących organizacji utrzymania ruchu przedsiębiorstw przemysłowych ze względu na ich „płaski" charakter. W oparciu o sformułowany problem badawczy zaproponowano sposób jego rozwiązania poprzez zastosowanie do modelowania procesów eksploatacji technik scenariuszowych. Następnie po dokonaniu przeglądu stanu wiedzy (literatury) w aspekcie budowy scenariuszy eksploatacyjnych, opracowano i przedstawiono szczegółowo procedurę prowadzenia badań, których efektem będzie opracowanie metodologii tworzenia scenariuszy eksploatacyjnych, z uwzględnieniem sposobu praktycznego ich wykorzystania. Artykuł jest wynikiem realizacji części badań w ramach projektu badawczego, finansowanego ze środków Narodowego Centrum Nauki nr 5636/B/T02/2011/40 pt.: Wykorzystanie metod scenariuszowych w modelowaniu procesów eksploatacyjnych.

Słowa kluczowe: *eksploatacja, utrzymanie ruchu, scenariusze eksploatacyjne, procesy eksploatacyjne, modelowanie.*

1. Introduction

Both in the theory of exploitation of technical systems, as well as in its practical application, much attention is paid to the problem of modelling. Current tasks of technical departments of most of industrial enterprises exceed traditional framework for planning, execution and settlement of maintenance works, particularly in terms of rationalization and optimization of decision-making processes both in short and long term.

In terms of rapid development of strategies and methods of maintenance management, as well as IT tools used for acquisition, collection and processing large amounts of data describing variety of technical facilities and conditions of their operation,

it seems to be possible and necessary to carry out the exploitation research related primarily to the development of the way of making optimal strategic decisions concerning, among others, issues technically, organizationally and commercially reasonable terms and conditions for maintenance tasks, withdrawal of objects from exploitation, long-term practices within exploitation philosophies or scopes of works.

This requires the construction of appropriate models of both technical objects, events, and exploitation processes carried out in an enterprise. These models should accurately reflect selected aspects of exploitation "reality" and must be based on foundations of modelling theory.

This article represents the next stage of research conducted on the possibility of support of exploitation decision making process in the industrial enterprises by the author at the Institute of Production Engineering of Silesian University of Technology. The research leads to develop a method of processes modelling, both their technical aspects as well as non-technical considerations of maintenance tasks (such as organizational, economic), which will use such models in practice.

2. Practical considerations of classical methods of exploitation processes modelling

It is assumed that the exploitation process is a set of structured operations, performed by technical objects overt their lifetime. Course of individual operations is determined by individual characteristics of objects and their organizational and technical environment, resulting in uniqueness of individual exploitation processes.

In order to identify and define the research problems considered in the article, it is necessary to identify and classify the exploitation processes precisely. The basis for such classification may be a way of describing (modelling), which determines the realization of particular tasks related to this process and regarding decision making as well. According to such criteria of classification, there are two basic ways to describe (models) exploitation processes [7]:

a) the exploitation process model as a sequence of events, by which certain tasks are undertaken and realized on the basis of information about specific events occurring at different moments of time (fig. 1),
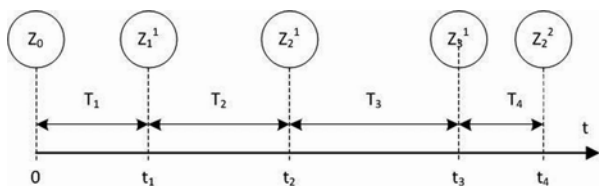

Fig. 1. The exploitation process model as a sequence of events [7]. Zij - exploitation events, Ti - time interval between events, ti - moments in which events occur

b) the exploitation process model as a series of states, by which maintenance tasks are undertaken and realized basin on momentory conditions of the object identified in equal intervals (fig. 2).

Considering the exploitation process model as a sequence of events, one can distinguish two types of possible events: intended and unintended ones. Each type of event determines consequently the procedure, reflecting different principles of
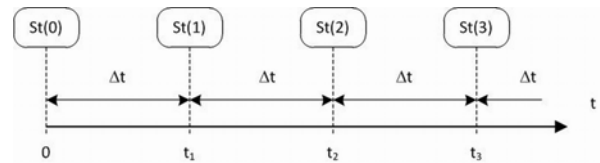

Fig. 2. The exploitation process model as a series of states [7]. St(i) - identified technical conditions, Δt - time interval between the moments of identification of the technical condition, ti - moments of identification of the technical condition

maintenance of facilities, comprised the maintenance strategy. Using the process model as a series of states to identify decision making in maintenance requires periodic (constant in time) control of technical conditions of the object and taking into account different procedures.

Exploitation practice shows that description of exploitation process related to specific item of technical objects requires most frequently simultaneous use of models discussed above. For example, technical objects, for which technical condition monitoring activities are carried out to (related to the exploitation process model as a sequence of states), may be subject to breakdown (events associated with exploitation process model as a sequence of events).

The aforementioned way of modelling exploitation processes in industrial practice results in development and implementation of general and dedicated solutions taking forms of operational strategies. In particular, basing on the relationship between exploitation processes and the way of decision-making in organizational and technical exploitation systems, it can be stated that most common decisions result from use of one of the following maintenance strategies:
1. breakdown maintenance strategy (BM), based on the exploitation process model as a sequence of unintended events,
2. preventive maintenance strategy, based on the exploitation process model as a sequence of unintended intended events (PM),
3. predictive maintenance strategy, which is based on the exploitation process model as a series of states (PM).

In industrial practice by linking different strategies with decision-making process regarding specific technical objects (and not necessarily the entire technological setting), all three strategies create maintenance policy of the company, where any of them is a dominant ona (is the basis for decision-making in relation to the majority or the most important technical objects), and the rest is supplementing it.

3. Identification of research problems and proposals for solutions

Exploitation process models, presented in the previous section and described in the literature, allow to solve important practical problems concerning use and maintenance of machinery and equipment. However, the above mentioned capabilities are subject to certain constraints, resulting from the character of these methods. The main constraint of this type is number of characteristics (parameters) possible to include in the model, that describe condition of the object/diagnostic signal or event. Such restriction significantly influences the accuracy of identification of a specific condition or event. It is also difficult to comprise qualitative features and non-technical aspects (organ-

izational and economic), which significantly affect the implementation of various maintenance tasks.

The most important constraints of the described ways characterizing the exploitation processes include:

- significant simplification of the models of processes in relation to organization, using technical objects, which are the subject of modelling,
- flat nature of the models showing the cause-effect relationships in a unidimensional way without taking into account the interaction with the environment in the form of additional non-technical aspects (eg. organizational or economic),
- difficulties with including qualitative characteristics and non-technical aspects (organizational and economic) in this type of models, which significantly affect the implementation of particular maintenance tasks (including maintenance management area).

The restrictions mentioned in the article hinder satisfaction of the needs related to effective use of typical models for the needs of decision making optimization in relation to the operating of technical objects by maintenance organizations of industrial enterprises.

Proceeding from the existing state of knowledge in the area and the conditions mentioned above, there can be formulated the main research problem of this article:

currently used models and methods of modelling have important restrictions which do not allow for effective use in optimization of decision-making related with operating of the technical objects and thus they are not an effective solution for evaluation and improvement of efficiency of maintenance management.

Solution to the problem of optimizing the decision-making process may be the use of scenario methods, using a multithreaded picture of reality at simultaneously possibility to look ahead of current time.

Scenario techniques belong to the forecasting methods that have been used in economic sciences for forecasting and strategic management. In technical sciences They have yet to be recognized.

Among several methods to create scenarios, in this case, the best seems to be the method proposed by H. Kahn, who called it as scenariowriting. This method consists of description of events and indication their logical and coherent consequences in order to determine the way of development of an object or situation.

The exemplary point of reference can be past or the current technical condition. The main emphasis is put on these events and situations, that could form the basis of future condition or sequence of events. In this way one gets a set of possible events or, in other words, images of the future.

Beside many ways of creating scenarios with the use of various methods, one can distinguish a limited number of types or variants in the described methodology. In this particular methodology, there are several types or variants. For considered area, possible, appropriate and reasonable to use are two of such types, which correspond to the needs and possibilities of exploitation process modelling [23]. Basing on specific hypotheses one determines possible events being an effect of current state or situation. This is called research scenario. This type of scenario corresponds to maintenance planning problems which are directly related to defining the maintenance strategy. In spe-

cific situations it is possible to use anticipatory scenario (fig. 3b), in which identified relations allow to specify the effects of the situation. This type of scenario provides the basis of analysis of past events, in particular failure analysis, where the most important element is to determine the reasons of the situation or failures in maintenance work.
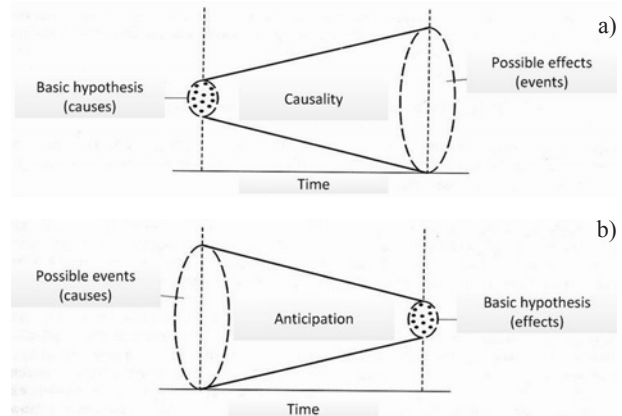

Fig. 3. Types of scenarios: a) research scenario, b) anticipatory scenario [23]

It can be noticed that, the method of construction of scenarios has much in common with the forecasting techniques. Starting from the current situation (a set of features describing exploitation processes), one can determine the factors influencing the future situations that are known. Relating these factors to the nearest future causes a slight change, while in longer periods, these changes may be significant. This is reflected both in changes in particular factors as well as in the influence of changes to individual objects or systems. Through the use of scenario methods for modelling of exploitation processes, one can show the way and scope of achieving possible alternative scenarios describing the effects of taken decisions.

As a part of further research it is proposed to use the events and processes scenarios, which provide qualitatively new approach in the area of modelling exploitation processes for the needs of effective decision making/maintenance management.

Key elements of the scenario methodology and features of exploitation area determine the necessary set of activities (detailed objectives), which implementation allows to solve the determined research problem. These activities include:

- defining the need and basis for scenario/collection of possible scenarios generation based on specific exploitation models, which may result from the reliability criteria, in this case (eg. a set of quantitative exploitation indicators),
- determining the internal and formal structure of the description of the scenario (identifying a set of parameters, the quantitative elements and features, defined as qualitative components of the situation/event),
- filling in scenarios for the object as such by mapping its environment (that is, by analogy, the author of the article proposes to describe the "scenery" in which scenario is "going on" - in addition to the same scenario),
- solution to the problem of practical use of scenarios in maintenance works, and optimization of decision-making processes relating to operating technical systems, taking into account multivariant issue of possible events

and behavioral simulation of objects in shorter and longer term.

4. The importance of exploitation process modelling with the use of scenario techniques

The problem of use of scenario techniques in exploitation occurs incidentally in the literature. It is mainly related to individual descriptions of case studies of scenarios in selected events (eg. in [24]). Detailed analysis of the literature, both domestic and foreign has shown that studies on the use of scenarios for the complex strategic aspects of the exploitation of technical objects are conducted primarily at the Institute of Production Engineering of the Silesian University of Technology. This is reflected in publications [8, 13, 16, 15, 18].

In terms of the issues discussed in the article, there are separate publications describing various elements associated with this topic, in particular:

1. modelling of selected elements of exploitation,
2. scenario methods and techniques,
3. computer aided maintenance management with strategic approach.

The first area is described quite extensively in terms of modelling the various elements of exploitation processes. Valuable in this area is [13], where the classification and review of the major exploitation models was carried out. Other items the literature describe a more or less detailed the various groups of exploitation models (event models eg. [7, 27], diagnostic models eg. [1, 2, 27, 28], technical objects and assets models [13, 19, 7], or exploitation process models [7, 13, 27, 22, 26].

The second area is widely described in the literature mainly from the viewpoints of economics, particularly in terms of strategic management [3, 4, 5, 6, 23]. The third area is described mainly in trade magazines, particularly in [17].

The results of the review of existing knowledge can be summarized in two aspects:

1. From the perspective of national and international publications and other studies, there are references to methods and issues which are parts of the proposed solution.
2. In complex terms, scenario techniques used for exploitation processes modelling can be considered a new issue not published both domestically and abroad.

5. The concept of research on the development of methods for the use of scenarios techniques in exploitation processes modelling

The research initiated and carried out by the author to develop the use of scenarios in exploitation processes modelling includes a wide range of work, both fundamental (theoretical) as well as industrial and developmental. On the one hand, this research is aimed at developing a methodology for construction of exploitation scenarios, as the basis and method of modelling and optimization of exploitation processes, and, on the other hand, at preparation of practical tools to use developed methodology in industrial environments.

Diagram of concept of carrying out such research is shown in fig. 4. Its individual components are described in the following paragraphs.
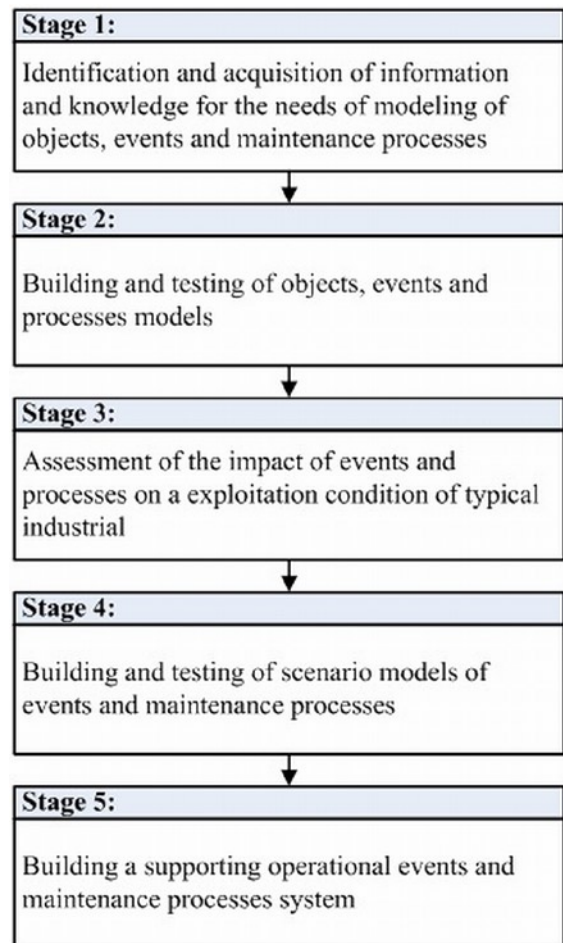

Stage 1:
Identification and acquisition of information and knowledge for the needs of modeling of objects, events and maintenance processes

Stage 2:
Building and testing of objects, events and processes models

Stage 3:
Assessment of the impact of events and processes on a exploitation condition of typical industrial

Stage 4:
Building and testing of scenario models of events and maintenance processes

Stage 5:
Building a supporting operational events and maintenance processes system

Fig. 4. Concept diagram of research

5.1. Stage 1: Identification and acquisition of information and knowledge for the needs of modelling of objects, events and exploitation processes

The first step of research is to acquire and collect an appropriate repository of information and knowledge about objects and all the technical and nontechnical "circumstances" of their operation, which form potential subject and scope of exploitation scenarios. The quality of the scenario, and thus the accuracy of forecasts results from the possibly large diversity and level of detail of information, therefore searching and acquiring should be orderly. The basis of such arrangement are the reasons based on the three levels related to the operations of selected objects: technical, organizational, decision-making and information exchange.

1. Technical level includes a set of features of the objects and performed with use of them. These activities, which aim at getting information of this type concern:
   • identification of complexity of technical objects which are the subject to modelling,
   • arrangement of maintenance procedures carried out on previously identified technical objects,
   • inventory of maintenance resources (labor, parts, tools, external services).
2. Organizational and decision-making level includes factors resulting from the way of functioning of the typi-

cal maintenance department, both internally as well as for external environment in wider context. The basis for this can be one of the models: a model of maintenance management [7] or the BCM model (Business Centered Maintenance) [9]. In this case, there are identified typical characteristics of standard maintenance department, allowing to gather a large amount of information and create knowledge repository for development of appropriate models, and exploitation scenarios.

3. The information exchange level includes criteria related both to the way of information flow within a typical maintenance organization, and to/from units of the external environment. Special attention is needed to identify the structure of information flow, which should begin with identification and distinction of the object that is maintenance unit (fig. 5).
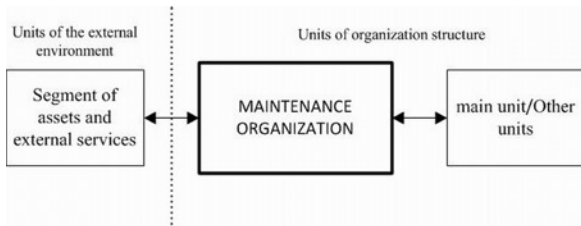
Fig.6. Hierarchical structure of exploitation information [7, 12]

Each of the levels may include a set of models, which is characteristic for aspects of the exploitation of technical systems, discussed here. Due to the hierarchy of exploitation aspects arrangement, causing dependencies between superior and inferior elements, building and ordering the models will be done starting from the lowest level. According to the layout, it can be assumed that:

- in the modelling of technical objects (object characteristics) it is necessary to use methods of structural and functional modelling, as well as methods of group and individual modelling,
- for exploitation events, it is necessary to model intended and unintended events on the basis of the existing tools in this area (event cards, event trees, logic trees, etc.) [2, 12] taking into account specificity of decision making process as a result or effect of a particular situation,
- exploitation processes will be the subject to modelling with the use of process maps and computer tools (eg. Aris Toolset), which allows to perform a simulation in relation to the prospective behaviour of technical objects.

The result of implementation of research in this stage will be technical and organizational set of models, as the basis of exploitation scenarios and system supporting operational events and exploitation processes.

Fig.5. Diagram of standard maintenance organization in the relationship with the environment

Such an object is a generalized and simplified model of information flow between the considered organizational unit and external entities. External units are both ones that are included in the organizational structure of the company (technical system), as well as ones which are outside of these structures. Inventory of the information flow should include identification:

- input and output of information,
- structure of information flow within the maintenance organization unit.

Research under this phase must be related to real existing enterprises, to take into account features that result from different industries. It is assumed that the information and knowledge will be collected simultaneously with performing the analyses starting from the exploitation activities and functions, through technical objects identifying and modelling, formulating strategic and prevention plans, specifying the organizational aspects, by defining elements of control in the end.

The result of the stage 1 should be a set of information and knowledge related to the functioning of a typical standard maintenance organization unit including computer tools (eg. CMMS/ EAM systems or process modelling tool - ARIS Toolset).

5.2. Stage 2: Building and testing of objects, events and processes models

The objective of research carried out within this stage is to build models of objects, events and exploitation processes. These studies must be carried out based on the results of stage 1 – repository of information and knowledge about objects and exploitation processes.

Due to the high diversity of models used in the area of exploitation, they will be built and organized on the basis of a diagram illustrating relationship between selected exploitation characteristics (fig. 6).
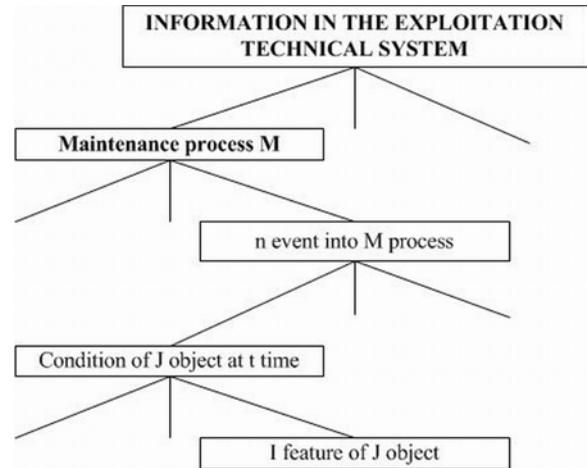
5.3. Stage 3: Assessment of the impact of events and processes on a exploitation condition of typical industrial enterprise

Research in this stage will be carried out with the assumption, that the exploitation condition of industrial companies (from a technical point of view) determined by rank indicators divided into specified classes) will allow to determine the effects of particular events and processes in the enterprise.

The subject of research will cover primarily identification of the classes that are basis for identifying the indicators of rank, using proposed set of measures allowing for quantitative evaluation of operating technical objects and functioning of servicing and maintenance department. Because of wide variety of this type of measurements, the aim of research in this area is assessment of their suitability, and then selection of these that will reflect the efficiency, quality and reliability of operation of analyzed technical objects best. Then, based on

models developed in stage 2, for each identified class there will be performed identification of particular events and processes and their impact on the state of and enterprises. This requires an extensive work, that will classify technical and non-technical (organizational, economic) factors of events and processes, influencing the company condition. That outlined study will be carried out in three ways:

- by introducing a "trial" object failure and simulating possible effects,
- by detailed analysis of cause and effect analysis of past events and activities realized as a result of this (exploitation processes), organized with including models that arise from Root Cause Failure Analysis (RCFA) methodology,
- by detailed analysis of current events and their effects from which the information will complement the research material (occurring along with the research).

After arranging the results of research and developing of cause-effect lists, events and processes will be assigned to the appropriate rank indicator.

5.4. Stage 4: Building and testing of scenario models of events and exploitation processes

During this stage, starting from the results of research done within the previous stages, there will be built exploitation process models, by introducing some elements of scenario methodology. It will be then possible to include multi-aspect nature of exploitation processes management and optimal decision-making. Due to specificity of exploitation, there will be taken into account two types of scenarios [4, 23]: scenarios of possible events and simulation scenarios.

This stage will be implemented in two steps:
1. Based on the selected way of scenarios creating, there will be designed a set exploitation scenarios for selected technical and organizational area. Selection of the area will be determined by the results of research carried out in the previous stages, in particular the developed objects, events, processes models (stage 2) and research on their influence on particular events and processes in the enterprise (stage 3).
2. Based on a set of developed scenarios of events and processes, there will be developed guidelines for use of scenario techniques as a basis for modelling exploitation events and processes. This will allow to make strategic decisions about This will allow to make strategic decisions about exploiting technical objects and functioning of maintenance department.

The result of the research in this stage will be a set of exploitation processes models built using scenario methods along with the guidelines that define their use in medium-and long-term planning and implementation of maintenance tasks.

5.5. Stage 5: Building a system supporting operational events and exploitation processes

The aim of the research in this stage will comprise development of principles for building a system supporting operational events and exploitation processes and building such a system, basingd on the results of previous stages. As a starting point for this research it is assumed that the system will consist of two layers:

- data and knowledge acquisition layer about the events and exploitation processes, in the form of components ensuring communication with data and knowledge sources in the enterprise information system,
- exploitation decision support layer, in the form of subsystem of control of flow related to events and processes, including exploitation scenarios, as a set of components of a system supporting operational events and exploitation processes.

The result of the research in this stage will be a prototype system supporting operational events and exploitation processes, which action will confirm practical feasibility of the assumptions in this research.

6. Summary

Taking into account the multi-aspect and multivariant nature of maintenance management process, reflected by the possibility of optimization seems to be more realistic in terms of scenario than in classical terms. The shape of the model and a set of criteria must take into account a wide range of technical and nontechnical aspects with as well as their connections "inside" modelled processes and with their closer and farther environment. It may be possible provided that an appropriate scenario building method is used to describe existing exploitation situation. The limit of complexity of the scenario description seems to be not in the same method but in the capabilities of the tools - particularly computer tools - used for practical applications of this method.

The presented method of modelling exploitation processes is a key element of the author's research carried out in the Institute of Production Engineering of the Silesian University of Technology. Justification for undertaking this subject can be specified in two fields:
1. in the exploitation theory,
2. in the area of methods and supporting tools in industrial practice.

The first area, according to the author, due to unreasonable lack of greater interest in the use of scenario techniques in the field of engineering sciences, despite the fact that these techniques have been known for many years and applied in the field of economic sciences. According to the author, the research discussed here can create added value for the area of machinery and technical object exploitation.

The second area emerges from practical and long-term author's experience in functioning of maintenance departments in a wide variety of industries (food, automotive, paper, chemical, water and sewage, etc.). Currently, the most important exploitation problems of engineers relate to long term planning, including moments of the replacement of worn and damaged components and whole objects, in terms of the need to continually costs reducing. These problems do not occur in technical isolation, but there must be also taken into account organizational, economic, and normative-legal aspects of the enterprise. Until now, these problems were solved in two distinct ways:

- technical, that is based on indicators of reliability and supplemented in some cases by the results of diagnostic tests,
- organizational and economic, that is based on indicators of cost of the enterprise's technical activities.

Use of scenario techniques in modelling of exploitation processes can be an effective tool for solving problems of planning and implementation of maintenance tasks in many industrial enterprises and therefore will enable implementation of specific actions for:

- implementation of modern maintenance management philosophy (TPM, RCM, WCM),

- building of intelligent system supporting operational events and exploitation processes,
- developing exploitation procedures in relation to the enterprises being at the design stage,
- performing different analyses (eg. failure analysis),

and above all
- optimizing exploitation decision-making process.

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