INFORMATION PROCESSING IN THE PROCESS OF MAKING EXPLOITATION DECISIONS

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Summary: Exploitation systems are constantly improved by management methods and information techniques. Machines in operation are subject to degradation controlled by diagnostic methods. Obtaining information on the condition and its processing for the purposes of legitimate exploitation decisions is elaborated on in many aspects, considered as new herein. This involves information selection, dedicated diagnostic systems, the system of agreeing on decisions and cause-effect modelling. Selected aspects of this subject were discussed in this publication.

Keywords: management, exploitation, diagnostics, redundancy, product lifecycle.

1. Introduction

Production system constitutes a deliberately designed and organized arrangement of material, energy and information used by men, for the purpose of manufacturing specific products – in order to meet diverse needs of consumers. Its proper functioning, in the light of production computerization and application of flexible production systems, almost starts a revolution in the methods of factory management. The practice of exploiting increasingly complex machinery shows that engineering knowledge, on a par with economic and organizational knowledge, becomes a necessity in market economy.

Detecting, measuring, recording and evaluating selected information and data on the condition of a particular system (organization, management, product quality, safety, environment, machinery exploitation) are used for the purpose of organization functioning, management and quality assessment (product, safety, environment, machinery) in terms of assumed task classification. The particularization of such decisions in the area of machinery degradation examination (task usefulness) at the stage of their exploitation is constituted by methods, procedures and measures of technical diagnostics, enabling a particularized (structural) assessment of system condition, generating a basis for further diagnostic-exploitation decisions [9, 10, 11, 12, 13, 14, 15].

The assessment of technical condition of machinery with the use of physical processes generated by it requires obtaining relevant information on the condition and associating functional parameters of the evaluated object properly, including a set of measurements and an evaluation of initial processes. The development of virtual techniques gives rise to numerous new solutions for modelling, simulating, collecting and processing of diagnostic information. Some of them were briefly presented in this article, including signal processing, statistical optimization of results and diagnostic deduction in making exploitation decisions.

2. Managing an exploitation system

The objective of economic development is to create conditions for the achievement of increased social productivity, taking into account criteria for environmental protection, quality systems, safety and modern IT technologies. An increasing amount of information produced in an enterprise in the areas of management, production and supporting processes requires their proper ordering, processing and reduction to an extent necessary to make rational decisions. Computer technique has taken control over all the spheres of enterprise activity; moreover, it undermined hitherto existing divisions and shook hitherto existing structure, as well as changed its surroundings.

Information technology development at various stages – from the design to machinery liquidation – including product lifecycle – is shown in fig. 1.

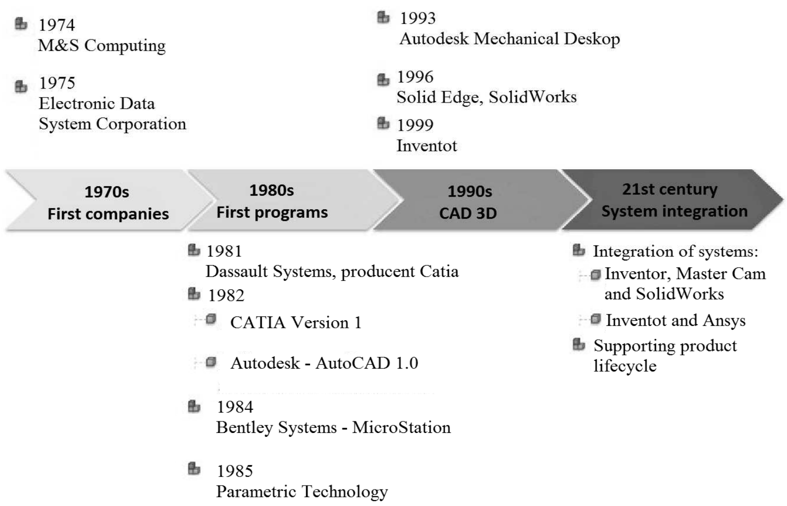


Fig. 1. The development of industrial information systems

An example of an enterprise information system highlighting the issue of maintaining machinery in motion, where logistics, exploitation, diagnostics and safety are most important. In such a system, the issue of monitoring machinery condition and other related partial problems in decision-making are integrated in company IT structure.

Taking into account variants of possible machinery exploitation strategies available in literature, their practical relevance for an enterprise can be assessed with the use of **utility indicators of efficiency**. They enable an assessment of damage development, as well as management through functional reliability.

Management functions in an enterprise are as follows: **planning, organizing, directing, motivating and controlling.**

Planning mainly focuses on:

1. developing a strategy for production system management,
2. forecasting demand, prices, ambient conditions and action,
3. designing a product and production process,
4. designing and selecting production capabilities,

5. planning product location,
6. designing production structures and arranging machinery.

Organizing production technology processing includes:

1. operation and work planning,
2. work measurement and standardization,
3. managing product development plans, production process and system changes.

Directing and motivating mainly include:

1. production system operation scheduling,
2. synchronizing deliveries and processing operations,
3. scheduling particular operations.

Controlling embraces an inspection of the whole processing system:

1. controlling material, semi-finished and ready-made product supplies,
2. controlling product quality,
3. controlling company's financial situation.

Keeping machinery in motion and assessing machinery condition, depending on the scope of diagnostics application in an enterprise, may include the following actions: corrective, preventive or forecasting, as shown in fig. 2.

Thus, the system of maintaining machinery usability takes advantage of all exploitation and management theory areas, with the help of IT technique with reference to acquiring, processing and transmitting information, which constitutes a basis for further diagnostic and exploitation decisions. More generally, monitoring and managing technical systems in an enterprise involves the issues of:

*** established:**

- enterprise management system,
- enterprise IT system,
- exploitation organization system in a logistic system.

**** implemented:**

- monitoring of enterprise functioning,
- monitoring of machinery condition through diagnostics and non-destructive tests.

Modern solutions of professional machinery condition monitoring systems for suitability maintenance are by such companies as: Bently Nevada (USA), Carl Schenck AG, Bruel & Kjaer, TECHNICAD – Gliwice, as well as many other commercial, partial information systems supporting machinery exploitation in a plant. Sensible and economically justified development of future enterprises embraces complex IT strategies in monitoring and management, handled by personnel trained in managerial and organizational issues.

Any company operating in a competitive free market economy should choose an appropriate management method ensuring a strategic advantage. This includes an analysis of description and relevance of management methods with reference to enterprise specificity, with their brief characteristics, principles of functioning and possible benefits. In view of a large number of established management methods (more than 130 according to various sources), such as: management by objectives (MBO), management by communication (MBC), management by innovation (MBI), management by delegation (MBD), management by results (MBR), management by quality (MBQ), strategic management (SM), management by motivation (MBM), management by participation.

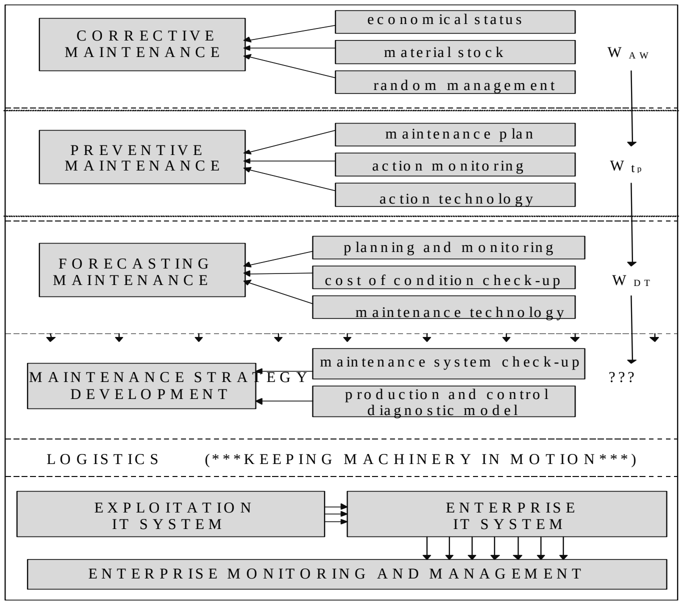


Fig. 2. Basic forms of keeping machinery in motion

(MBP), with different: property forms, locations, branches and employment size – an analysis of the distribution of their use frequency indicates that management by objectives (MBO) and management by quality (MBQ are the most frequently used methods (fig. 3).

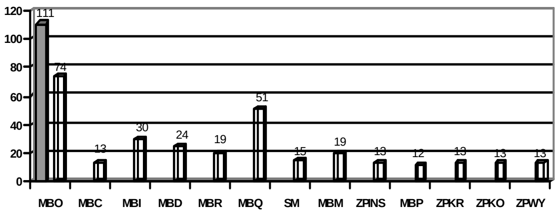


Fig. 3. The use frequency of management methods applied in organizations [6]

A tool for shaping action accurateness with reference to machinery suitability assessment are monitoring and technical diagnostics, generating information necessary to manage their exploitation – fig. 4. Quality supported by information techniques has become the central problem of modern management. It is the whole of product characteristics and services affecting their ability to meet identified and potential needs.

Available commercial “product lifecycle” programs include a description and principles of managing the lifecycle of a machine at the stages of evaluation, design and construction, manufacturing and operation.

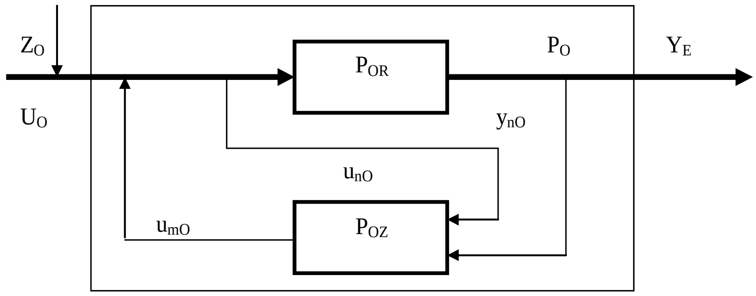


Fig. 4. The idea of machinery exploitation management in an enterprise: P_{OR} – exploitation working subsystem, P_{OZ} – exploitation management subsystem, U_O – input, Y_O – outputs, Z_O – disruptions, u_{no}, y_{no}, u_{mo} – signals: input, output and steering respectively

At the stage of design, the following are used: Autodesk, AutoCad, CAD, CAE (MES, FLUENT, ADAMS), PDM (documentation management), MICROSTATTION, CATIA, SOLIDWORKS, SOLIDEDGE, INVENTOR and ANSYS. In manufacturing, the following are available: CAM, IRIS, UIC. For exploitation description, the following programs can be used: ARETICS, CMMS Machine, TPM, AGILITY, MAXIMO, SUR-FBD, EUROTRONIC, THETA-CONSTELLATION, PREKION, PLAN-9000, "MACHINE" SYSTEM, PLAN9000 SYSTEM, REPAIRING SYSTEM API PRO, IMPACT XP 217 SYSTEM, IFS SYSTEM, ISA SYSTEM – BPCS. Product lifecycle integration is described by PLM, LCM, engineering knowledge management – KM, CATIA.

3. Initial data processing

The observation of progress in wear and tear of an object is based on measuring various symptoms of the technical condition and comparing them with allowed values established earlier – for a specific symptom and in a particular application. The process of object wear and tear is usually not one-dimensional, and the dimension of damage degree increases with the degree of machinery construction complexity. This radically improves the dimensionality of condition vectors, signal and interference vectors. Diagnostic information available in the check-up becomes redundant, dimensionally complex and difficult to process.

This study presents the problems of information redundancy, assessment of individual measurements of diagnostic signal and multi-dimensional processing of diagnostic information in program research as key issues.

In practical applications, the pre-treatment of measurement data is an essential step in data classification, having impact on both the effectiveness of distinguishing between conditions, speed and construction simplicity, as well as learning the cause-effect model and its subsequent generalization. A recorded time signal of the tested process moved to an Excel spreadsheet is the basis for further processing, for example in the field of time, frequency and amplitude, giving many measurements enabling the decomposition of the output signal to signals of growing individual disruptions. The decision-making process consists of a series of operations starting with obtaining information on machinery status, its gathering and processing, until selecting and forwarding a fixed decision for implementation. At the beginning, however, three types of initial data processing need to be distinguished: data transformations, filling in the missing values and dimensionality reduction.

Data transformations – analyzing experimental data is associated with various types of measurement scales, which may be symbolic or numeric. In case of diagnostic information processing systems, most frequently all the features that describe analysed objects have to be numeric.

In the case of classification models using distance as a measurement of similarity it is very often the case that individual features characterise a physical state on the basis of various physical quantities, having different ranges of values, and, as a result, they can have a different impact on distance. A few transformations unifying the influence of individual features to the value of distance can be applied.

Normalization. Conducted according to the following formula:

$$X_N = \frac{x_i - x_{i\min}}{x_{i\max} - x_{i\min}} \tag{1}$$

where: x_{imax} - maximum value in a set for feature,
x_{imin} - minimum value of feature.

As a result of normalization, vectors with feature values from the range [0,1] are obtained. This transformation does not take into account value distribution of a given symptom; therefore, in the case of the appearance of several symptoms with values significantly different, most values are pressed narrow range as a result of normalization.

Standardization. The use of value distribution in single symptoms leads to a transformation known as standardization, according to the following relations (2).

$$X_S = \frac{x_i - \bar{x}_i}{\sigma_i(x)} \;; \quad \bar{x} = \frac{1}{n}\sum_j^n x_j^i \;; \quad \sigma_i(x) = \frac{1}{n-1}\sum_j^n (x_i^j - \bar{x}_i)^2 \tag{2}$$

As a result of this transformation, symptoms with an average value of x = 0 are obtained, and standard deviation σ = 1, so that all the symptoms have an equal share with respect to the value of information.

Precision constant – takes into account the range of variation and an average value of measured parameters and provides non-dimensionality, as per the following relation:

$$p_i = \frac{\bar{x}_i}{w_i} \tag{3}$$

Symptom sensitivity w_i expressed as one number together with an average value ensures non-dimensionality and changeability range:

$$w_i = \frac{x_{i\max} - x_{i\min}}{\bar{x}_i} \tag{4}$$

Ensuring the possibility of mutual further consideration of data obtained in measurement is an important and necessary step to make at the very beginning.

4. Ideal point method – OPTIMUM

Diagnostic signals measured in different ways reflect observation space, and, in an indirect way, damage development in a machine – fig.5. With the use of optimization techniques, sensitivity of measured symptoms to condition changes can be characterized based on measuring the distance from the ideal point. Distinguishing the fault is possible – according to mathematical formalism – after projecting constituent symptoms on the axes *x*, *y*, *z* respectively.

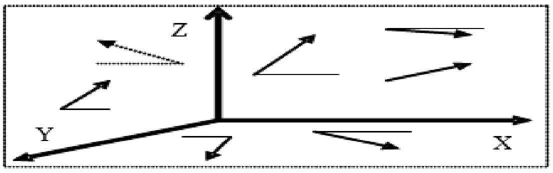


Fig. 5. Multi-dimensional observation space

The following algorithm makes statistical assessment of individually elaborated diagnostic symptoms possible, resulting in a final ranking of their sensitivity and relevance. The following steps of this procedure include:

1. creating an observation matrix from measured symptoms: $s_1, s_2, s_3, \ldots, s_m$;
2. statistical assessment of symptoms with the use of various criteria, i.e.:

- symptom changeability:

$$f_1 = \frac{s_j}{\vec{y}} \tag{5}$$

where: S_j – standard deviation,
$\bar{y}$ - average value.

- assessment of symptom sensitivity to condition changes:

$$w_i = \frac{x_{i\max} - x_{i\min}}{\bar{x}_i} \tag{6}$$

- correlation to the technical condition, run (determination of the correlation coefficient: symptom-condition):

$$f_2 = r\,(y,w); \qquad r_{xy} = \frac{1}{n-1} \frac{\sum_{i=1}^{n} (x_i - x_{sr})(y_i - y_{sr})}{\sigma_x \sigma_y} \tag{7}$$

To make considerations and the presentation of results on surface easier, two selected indicators of quality are sufficient.

3. Making further maximization and normalization of adopted indicators of quality signals, we obtain statistical characteristics of their sensitivity (f_1^*, f_2^*), which further allows to determine the coordinates of an ideal point. This allows distance determination of single signal measurements from an ideal point, according to the following relation:

$$L = \sqrt{(1 - f_1^*)^2 + (1 - f_2^*)^2} \tag{8}$$

4. General sensitivity coefficients (weights) for each tested signal are determined as per the relation:

$$w_i = \frac{1}{\frac{1}{L_i} \cdot \sum_{i=1}^{n} L_i}, \qquad \text{where: } \sum w_i = 1 \tag{9}$$

The presented algorithm can be easily performed in Excel, obtaining a quality arrangement of measured symptoms. Fig. 6 shows the final result of this procedure for sample measurement data. Distance points of each measurement from an ideal point (1, 1) indicate the sensitivity of assessed signal measurements, with the points closest to (1,1) being the best symptoms.

Having highlighted statistically good symptoms, you can build cause-effect models at the stage of inferring the condition. The quality of the model depends, however, on the number of measures taken into account, which, indirectly, in the simplest regression models, can be evaluated with determination coefficient R^2.

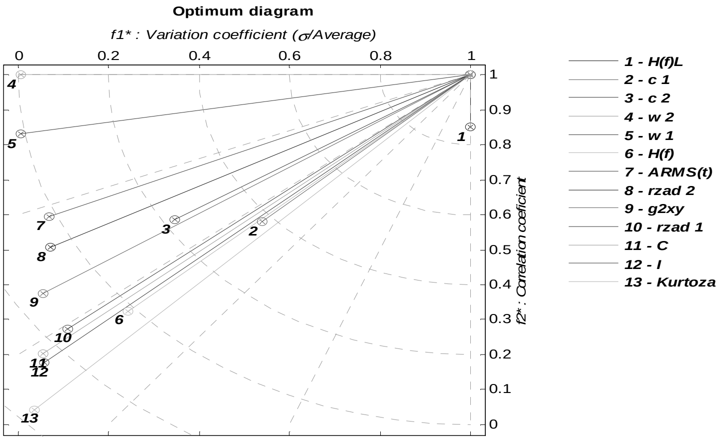


Fig. 6. Ideal point method outcome - *OPTIMUM*

5. Multi-dimensional system observation – SVD

SVD (Singular Value Decomposition) is a numeric procedure for multi-dimensional tracking of changes of object condition. It detects developing damage and selects maximally informative condition symptoms in a given situation.

Let's take into account a complex mechanical object operating in time$0 < \theta < \theta_b$, where evolutionarily several independent **defects** are developing, $F_t(\theta)$, t=1,2,..u. Their development can be handled by observing the phenomenon field, creating a row vector of technical condition symptoms; $[\mathbf{s_m}] = [\mathbf{s_1,...,s_r}]$, with different physical nature. For the purpose of tracking changes in the technical condition of an object, one can perform dozens of equally distant value readings of the vector in time; θ_n, n=1,...p, $\theta_p \le \theta_b$. In this way, further rows of symptom observation matrix (SOM) are obtained. We already know that the maximum of diagnostic information can be obtained from the matrix if all the initial readings are centred (subtracted) and normalized to the original value $\mathbf{S_m(0)} = \mathbf{S_{0m}}$ of a given symptom. We thus obtain a non-dimensional symptom observation matrix:

$$O_{pr} = [S_{nm}], \qquad S_{nm} = \frac{\mathbf{S}_{nm}}{\mathbf{S}_{0m}} - 1 \tag{10}$$

where: bold marking represents the original dimensional symptom values.

For the purpose of describing system lifecycle, we hale a non-dimensional observation matrix O_{pr} of **r -** columns resulting from the number of observed symptoms and **p** lines resulting from the total number of consecutive observations. To the non-dimensional observation matrix the procedure of distribution in relation to specific values:

$$O_{pr} = U_{pp} * \Sigma_{pr} * V_{rr}^{T}, \tag{11}$$

where: (T- transposition) U_{pp} is a p - dimensional orthogonal matrix of specific left-sided vectors, and V_{rr} is a r - dimensional orthogonal matrix of specific right-sided vectors and In the middle – a diagonal matrix of specific values Σ_{pr} with the following properties:

$$\Sigma_{pr} = \mathrm{diag}\ (\sigma_1, \ldots, \sigma_l), \text{ where: } \sigma_1 > \sigma_2 > \ldots > \sigma_u > 0 \tag{12}$$

and: $\sigma_{u+1} = \ldots \sigma_l = 0$, $l = \max(p, r)$, $u = \min(p, r)$.

This means that of r - measured symptoms one can obtain only $u \le r$ of independent information on growing damage. Such a decomposition of SVD observation matrix can be conducted after each observation; n = 1, ..., p, and thus the evolution of defects $F_t(\theta_n)$ in an object can be monitored.

One damage F can be described by a pair of new values; SD_t and σ_t.. The first one is a generalised symptom of damage **t**, which could be called a discriminant of this damage and could be obtained as a right-sided product of observation matrix and vector $\mathbf{v_t}$ [4]:

$$SD_t = O_{pr} * \mathbf{v_t} = \sigma_t \cdot \mathbf{u_t} \tag{13}$$

Since vectors v_t and u_t are normalized to unity, the length of vector SD is equal to its energetic norm and equals:

$$\mathrm{Norm}\ (SD_t) \equiv \| SD_t \| = \sigma_t \tag{14}$$

Therefore, for a specified lifetime θ use advancement of damage F_t can be reflected by a special value $\sigma_t(\theta)$, whereas its instantaneous evolution - by discriminant $SD_t(\theta)$. The equivalence of new measures of SVD is postulated to the characteristics of damage areas, throughout the whole lifecycle θ of an object:

$$SD_t\,(\theta) \sim F_t(\theta), \text{ with the norm } |F_t(\theta)| \sim |SD_t(\theta| = \sigma_t(\theta) \tag{15}$$

$SD_t(\theta)$ can also be called a damage profile, whereas $\sigma_t(\theta)$ its advancement. Fig. 7 shows the SVD idea.

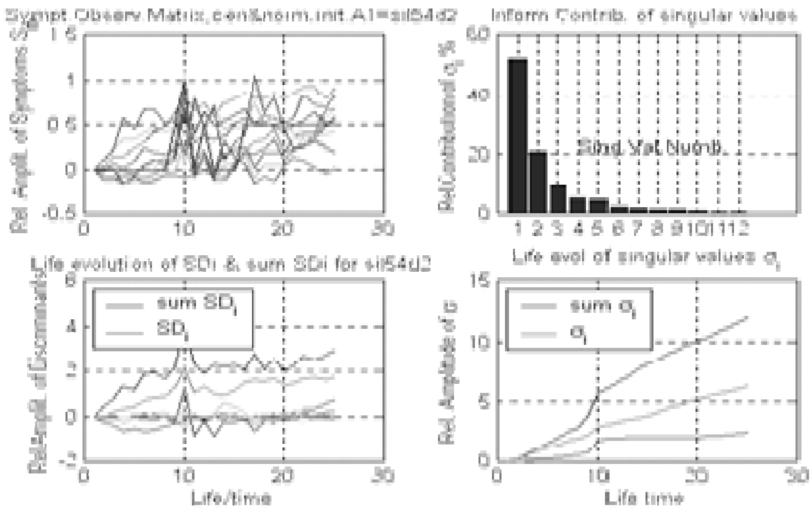


Fig. 7. Diagnostic information contents with independent damage in observation matrix, and detected independent discriminants SD_i and advancement measurements σ_i

The target of SVD is also to select maximally informative symptoms measured in a given diagnostic observation. From the observation matrix $O_{pr} = [S_{nm}]$ one can define two square r and p- dimensional covariance matrices, as below ($*^T$ – the transposition of the matrix, vector):

$$W_1 = (O_{pr})^T * O_{pr}, \text{ and; } W_2 = O_{pr} * (O_{pr})^T \tag{16}$$

Solving own issues of these matrices (EVD) shows that in this way the wanted specific vectors of the observation matrix SVD and squares of the specific values can be obtained:

$$W_1 * v_\nu = \sigma^2_\nu * v_\nu\ , \ \nu = 1,...r; \text{ and; } W_2 * u_i = \sigma^2_i * u_i\ , \ i = 1,...p. \tag{17}$$

Thus, solving the two own issues (Eigen Value Decomposition - EVD) of both covariance matrix defined on the observation matrix, we obtain the same result as in procedure SVD; squares of specific values instead of their original values are the only difference.

An example of the application of these considerations is a diagnostic observation of a 12 cylinder traction diesel engine, and the results are shown in Figure 8. The image in the upper left corner shows 12 measured symptoms creating a complexity of information, which, however, after being processed by SVD, is easy to decode into two main types of damage, because σ_1 and σ_2 constitute ca 50% and 20% of all diagnostic information in the observation matrix (image in the upper right corner) measured as a quotient of the values of a given σ_i to the sum of all specific values. Moreover, the first damage SD_1 (lower left corner) almost monotonically increases, while the second one is unstable and begins to grow only after the 20th measurement (200 thousand kilometres), which can also be seen in the course of intensity of damage σ_2, in the lower right corner.

6. Information system of identification tests

The possibility of rapid identification of damage while diagnosing the elements affecting the functioning of objects was the basis for the creation of SIBI program shown in fig. 8.

This program is an attempt of software implementation for the following purposes: acquisition of vibration processes, their processing, testing co-dependencies of vibration processes, testing symptom sensitivity, statistical inference, and visualization of analysis results.

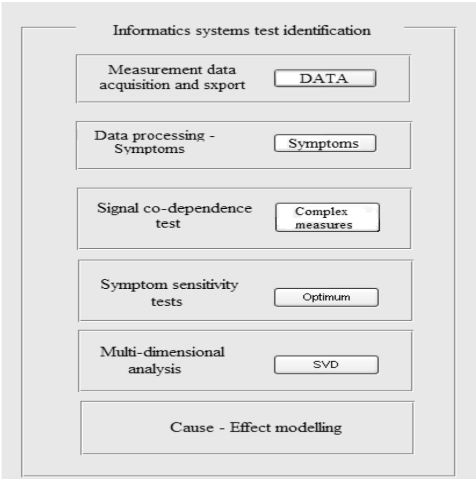
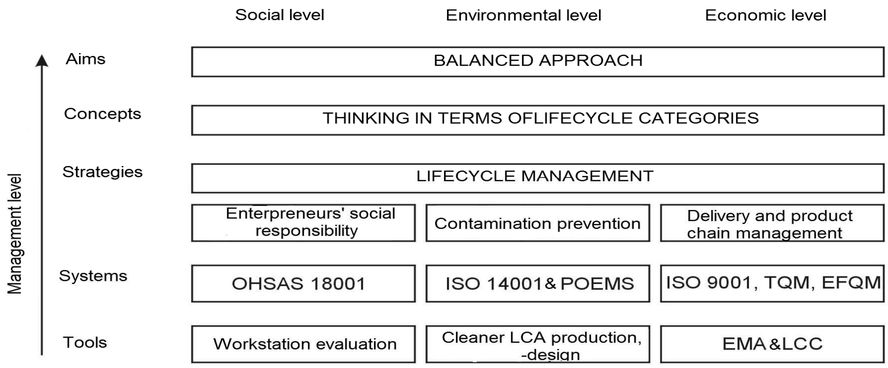


Fig. 8. Main dialog window of SIBI program

7. Managing product lifecycle

The procedures of rational exploitation can be characterized socially, environmentally and economically – fig. 9.



The explanation of shortcuts: OHSAS - safety and professional hygiene, POEMS - The system of the environmental management be well-versed in on the product, TQM - the total management the quality, FFQM - European Foundation for Quality Management, LCA - life-cycle analysis, EMA - Employers and Manufacturers Association., LCC - opinion of the costs of the cycle of the life

Fig. 9. LCM (Life Cycle Management) [21]

On the market there are many CMMS systems (Computerised Maintenance Management Systems) in a wide range of prices and possibilities. An important issue for enterprise decision-makers is the choice of proper system supporting motion maintenance services. The analysis of methods of evaluation and selection of systems of this type [22] and the subjective-scoring method of the assessment of the environmental usability of commercially available computer programs are shown in fig. 10.

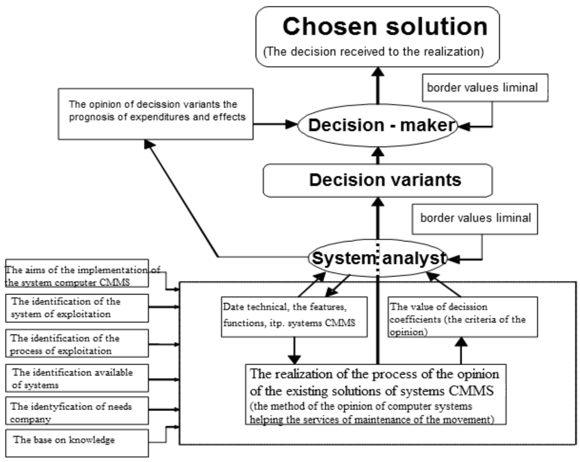


Fig. 10. The algorithm of information system selection for exploitation monitoring [22]

8. Conclusion

Selecting a method for the specificity of enterprise business depends on a number of internal or external factors. It is impossible, however, for an organization to survive without adopting any of the methods reducing the chaos and randomness of decision-making rules to a minimum. The methods should be well identified before implementation, and the decision on their implementation should be fully deliberate.

Basic assumptions of this article include the following:

1. the need to introduce modern management strategies in enterprises,
2. the superiority of obtained information in steering an enterprise,
3. highlighting machine exploitation management system in enterprise logistic system, including machinery exploitation tests.

The problems of diagnosing complex technical objects are still in development, and the procedures for acquiring and processing diagnostic information are continually refined. This article discusses the reduction of redundancy for individual condition symptoms and for a multi-dimensional condition test.

A new, simple and effective method of sensitivity assessment for individual measurements of condition was proposed – the *OPTIMUM* method; moreover, the essence of the SVD method, SIBI program and guidelines for the selection of rational commercial programs in the field of machinery exploitation were explained.

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