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Improving the Quality of Maintenance Processes Using Information Technology

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Abstract: *In essence, process of maintaining equipment is a support process, because it indirectly contributes to operational ability of the production process necessary for the supply chain of the new value. Taking into account increased levels of automatization and quality, this process becomes more and more significant and for some branches of industry, even crucial.*

Due to the fact that the quality of the entire process is more and more dependent on the maintenance process, these processes must be carefully designed and effectively implemented. There are various techniques and approaches at our disposal, such as technical, logistical and intensive application of the information-communication technologies. This last approach is presented in this work.

It begins with organizational goals, especially quality objectives. Then, maintenance processes and integrated information system structures are defined. Maintenance process quality and improvement processes are defined using a set of performances, with a special emphasis placed on effectiveness and quality economics. At the end of the work, information system for improving maintenance economics is structured. Besides theoretical analysis, work also presents results authors obtained analyzing food industry, metal processing industry and building materials industry.

Keywords: *quality, maintenance process, information technology, improvement, maintenance economics, effectiveness.*

1. INTRODUCTION

Work equipment maintenance processes become more and more significant for achieving organizational objectives. Although they are classified as a support processes, increases in automatization and rising product quality demands, their influence is rising progressively.

If we observe process map in a manufacturing organization, maintenance processes affect the overall product quality, process and organization in the following two ways:

- increasing operational readiness, effectiveness and quality of elementary production processes and
- improving maintenance processes quality

First way is dominant because the total number of the maintenance workers and maintenance budget is up to 5% of the entire

organization. Exceptions to this rule are maintenance in the mines, metal processing enterprises and process industries, where these percentages are significantly higher.

In these conditions, it makes sense to use different approach to increase maintenance process quality.

Simultaneously, principal paradigms in the field of maintenance were changing, starting with corrective maintenance, continuing through prevente maintenance and ending with entirely productive maintenance [1, 3]. In practice, organizations use some combination of these maintenance concepts.

From the large number of works from this field, authors analyzed works which dealt with maintenance management using holistic approach [4], business processes risks and role of maintenance [5], role of benchmarking in improving maintenance management [6], industrial systems maintenance modeling [7], scheduling of preventive activities in the actual production of limitations [8], maintenance policies evaluation [9] and use of AHP method for efficient maintenance system [10]. Also, authors analyzed a large group of works from the field of improving maintenance processes and relation between quality and maintenance. Work [11] analyzes elements of Japanese strategy and the role of TPM. Works [12, 13, 14, 15, 16, 17 and 18] analyzes different aspects of maintenance quality, relations between maintenance processes and product quality and organization (QMS – Quality Management System) and wider (IMS – Integrated Management System).

If we observe maintenance process quality (Q), we can notice that it is most often defined using suitable performances. Performances used most often are related to maintenance costs (independently or in conjunction with other expenses or income), maintenance efficiency and similar. Besides quality, as the goal of maintenance, maintenance process also has to satisfy productivity (P) and flexibility (F) objectives. This triad of objectives P, Q and F are the basis for modeling maintenance processes with the ultimate goal of achieving optimal organizational objective.

Large number of works related to effectiveness [19], maintenance effectiveness [20], holistic approach to measuring performance effectiveness [21], efficiency and effectiveness of measuring maintenance performance [23], cost-benefit analysis [24], demands and challenges in measuring maintenance performance [25], multi-criteria, hierarchical framework for measuring maintenance performance [26], application of BSC in measuring maintenance performance [27]. This group of works also includes works addressing measurement and analysis of the performance effectiveness [28, 29, 30, 31] and especially maintenance economics [32, 33, 34 and 35].

Scope of this work is maintenance process quality and opportunities for improving maintenance process quality through application of information technologies. Significant number of authors researched this field [36, 37, 38, 39, 40], starting with capabilities of information technologies for monitoring, effective implementation and decision-making in maintenance process. Quality was observed as the output characteristic of this maintenance process supported by application of information technology. Authors have chosen different approach, its principal elements being the following:

- taking into account the organization's objectives and defining components of the process goals,
- after definition of the maintenance process goals in the previous step, component objectives P, Q values are defined and F of the maintenance process,
- maintenance process is modeled in such a way to achieve these objectives through application of various planning methods and process analysis (most often through effectiveness and maintenance costs),
- process modeling is often accomplished with the support of information technologies,
- application of the chosen information technologies results in design of the software for improving maintenance processes,
- in accordance with the new project solution, maintenance processes design in detail and applied in practice with continues performance monitoring,
- in the event of deviation of the planned objectives from the

maintenance process planned values, corrective measures are implemented.

This work presents approach and characteristic results of research and application of this concept in enterprises working in the field of food industry, construction and metal processing. Due to the limited space, this work describes in detail third and fourth activity of the proposed concept.

2. MAINTENANCE PROCESS IMPROVEMENT APPROACH

2.1 Process improvement basics

Process quality improvement can be achieved through:

- continuous improvements, which is a key demand from the ISO 9000 series standards and
- radical process improvement (reengineering process).

If we determine through use of benchmarking process that observed organization (O) significantly lags in quality levels behind control sample organization (A), continuous improvement concept will not be sufficient to close this „gap". Determined, planned and timely approach to reengineering process must be applied [41, 42, 43].

Both approaches are based on the use of well-known Deming's **PDSA Cycle.**

Using process objective matrix [44], process characteristics are obtained, those that have process quality characteristics as well as those related to effectiveness and efficiency of the process and entire organization. Analysis of the process characteristics is conducted in the following phase and characteristics that are determined to be successful by nature are determined. Answer to the second question is provided this way (Figure 1).

These activities can occur during the P-part of the **PDSA** cycle, or during the S-part after the influence of quality characteristic changes on process objectives, is analyzed. Results of this analysis should facilitate selection of the changes which are in accordance with the policy and quality objectives and limitations in the organization.

PDSA cycle can improve the level of quality during each phase of the planning, design and detailed design of the process.

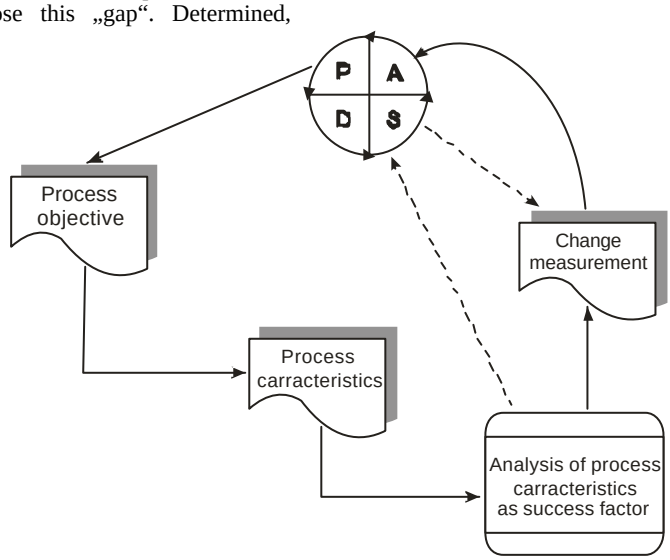


Figure 1. Process quality improvement procedure

From previous, we can conclude that quality improvement process has four phases:

1. *preparation for changes,*
2. *planning of the changes,*
3. *design of the changes and*
4. *application of the changes in the evaluation of the effects of the changes* [1].

This work will emphasize *design of the changes* aspect of the process, which consists

of sub-processes interconnected as shown on the *figure 2.*

Designing changes is accomplished in 6 steps (sub – processes). Out of the previous phase (planning of the changes), we enter step 1. (Identification of the existing business processes). The last (step 6.) is the entry into the following phase (evaluation of the changes).

Primary flow activities, depicted with a solid line in figure 3., marks the primary order of activities and secondary feedback of information and correction of inputs for the following processes.

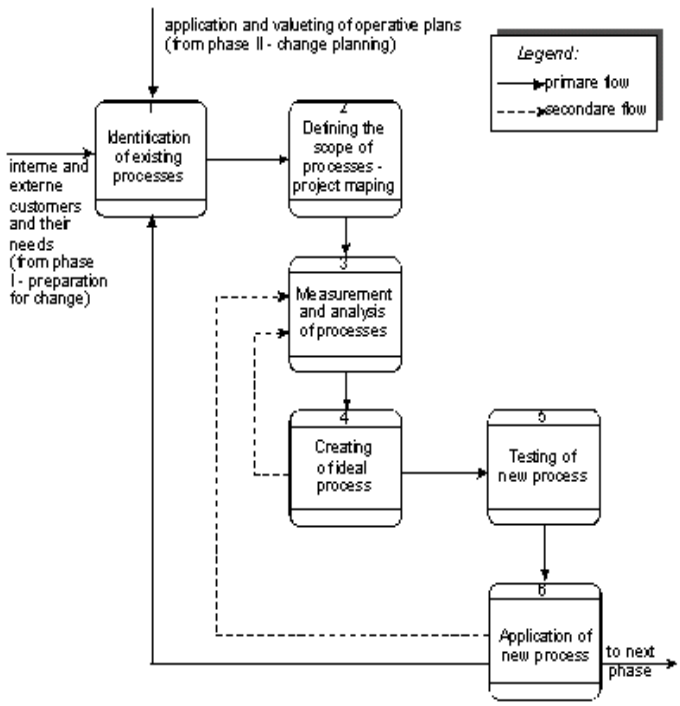


Figure 2. Steps for designing changes

2.2 Measurement of the critical processes and maintenance process metrics

2.2.1 Measurement of the critical processes

Measurement of the critical processes is conducted by the reengineering team and operational management on the basis of determined characteristics of each process. It is usually started with measurement of the most influential critical process and then according to the measurement procedure, other critical processes are included.

Process metrics can have various forms [45]. Figure 3. shows the flow of the process metrics application

Based on the measured process characteristics and process objectives, various numerical based and graphic summaries are created. This facilitates the procedure for evaluating process characteristics.

Process characteristics evaluation

This evaluation is conducted using various methods, most frequent being process of evaluation and benchmarking.

Benchmarking outputs are various. These are primarily comparisons and gaps when compared to the sample organization. Then, there are proposals for improvements obtained through research of the organization and based on the customer demands.

Process evaluation can be conducted in various ways, using various methods (i.e. value

analysis, expenses deviations, designed process ranking system by IBM).
Based on the last method, process evaluation is conducted on 5 levels.

Matrix and maintenance process quality evaluation

Significant characteristics of the maintenance process are:

K1. Maintenance work orders completion:
Number of active maintenance work orders (tasks-number of items) / Number of completed maintenance work orders (number of items).

K2. Maintenance over budget (%).
The data is obtained from financial plans, quarterly and biannual financial reports (created by the economic and finance sectors and part related to maintenance and delivered to the chief of maintenance)

K3. Maintenance flexibility:
S **delays/** S **planned/ projected maintenance time x 100 (%).**

K4. Operational readeness (OG):
OG = Tur / (Tur + Tuo), where Tur - denotes up-time and Tuo - denotes down-time
Data is obtained from the records of measuring and monitoring characteristics of: machinery and equipment maintenance, building maintenance, installation and infrastructure maintenance.

K5. Increasing percentage of the preventive maintenance:

PO = total hours of PO /total hours of maintenance
Data is obtained from the records of measuring and monitoring characteristics of: machinery and equipment maintenance, building maintenance, installation and infrastructure maintenance, delivered monthly to the head of maintenance by responsible personnel. Head of personnel calculates percentage increase over the previous period.
Head of maintenance is responsible for monitoring and follow up of the process' performance as well as personnel in the other organizational units.
Table 1 is used to calculate the mark (median).
Report on measurement and monitoring is delivered to the technical sector manager.
Evaluation of the process performance is conducted quarterly, good application of corrective or preventive measures as needed.

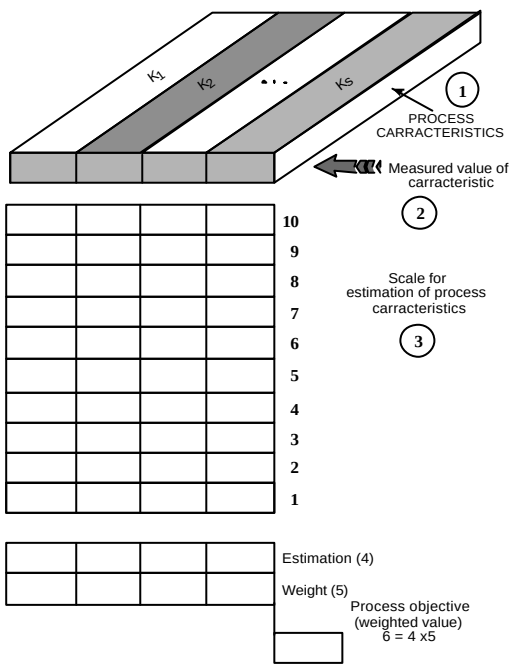


Figure 3. Process metrics flow

Table 1. Values of the maintenance quality characteristics

K1 - Completed	K2 - Excess of the maintenance expenses	K3 - FO	K4 (%)	K5 - Percentage increase PO	Mark (estimation)
0	< 1	0	100	> 50	10
1	1-5	1	90	40-50	9
2	5-10	2	80	30-40	8
3	10-15	3	70	25-30	7
5	15-20	5	60	20-25	6
10	20-25	10	50	15-20	5
15	25-30	15	40	10-15	4
20	30-40	20	30	5-10	3
25	40-50	25	20	1-5	2
30	> 50	30	10	< 1	1
5	4	6	4	2	Mark obtained (estimated) - DO
0,2	0,2	0,2	0,2	0,2	Weight (P)
1.0	0.8	1.2	0.8	0.4	Value of the characteristic VK = DO x P
Process objective (UP): UP = S VK = 4.2					

3 MANAGEMENT OF THE MAINTENANCE PROCESS SUPPORTED BY THE INFORMATION TECHNOLOGIES

Maintenance expenses, as part of the maintenance economics, have varying structure caused by diverse maintenance processes, certain components and maintenance resources, priorities etc. Each one of the outlined methodologies, regardless of the level of detail, must be improved with monitoring and reporting methodologies on maintenance expenses to be used in practice. In some organizations, maintenance function is responsible for this system, in the others quality maintenance function and in the most advanced, this is achieved automatically using information system for managing operational costs, parts of which are maintenance costs. In the last scenario, problem occurs because all the elements of expenses and losses that occur during maintenance are not incorporated in the integrated software.

Because of this, authors of this work propose the following phases in the development of the information system for managing maintenance expenses:

Phase I: development of the methodology for measuring, monitoring and reporting on maintenance economics,

Phase II: creation of the procedures and instructions for ensuring quality in maintenance procedures, according to the ISO 9001:2000,

Phase III: development of the information system for managing maintenance with module for managing maintenance economics,

Phase IV: development of the integrated information system in the Internet environment.

Observed from the practical standpoint, majority of the organizations in Serbia are currently in the phase I, only certified organizations (approximately 1450) are in the phase II, considerably smaller number (less than 150 according to the authors estimate) is in the phase III and there is even smaller number of organization currently in the phase IV (less than 50).

Based on this, authors decided to point out the measurement problems in this work first, and then, in the second part of this work, to show alternative solutions of the module for managing maintenance economics.

3.1 Model for measuring, monitoring and reporting on maintenance economics

Maintenance expenses, are a significant part of the production costs. This portion varies from 50% all the way up to 50% of production costs. Therefore, it is often that efficiency of the projected maintenance system is reflected in maintenance costs. Problem of different ways of showing the overall maintenance expenses, including or excluding various component maintenance exp enses, frequently appears during this process.

Having this in mind, authors decided to use conceptual modeling approach in developing this model off maintenance economics.

Maintenance costs are divided into two groups:

- direct maintenance expenses and
- indirect maintenance expenses.

Figure 4 shows basic conceptual model of maintenance economics.

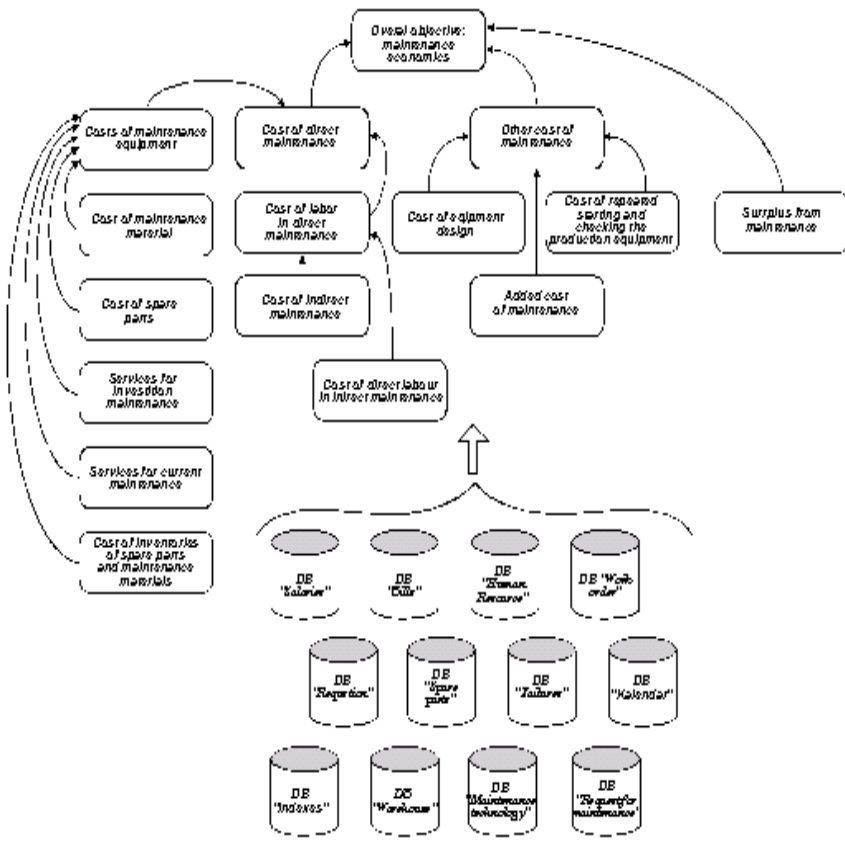


Figure 4. Basic conceptual model off maintenance economics

Maintenance costs are divided into:

1. maintenance material costs,
2. maintenance spare parts costs,
3. investment maintenance service costs,
4. current maintenance service costs,
5. costs for warehousing spare parts and materials,
6. costs of skilled labor performing immediate maintenance:
   - costs for direct labor on equipment maintenance and
   - costs for indirect labor on equipment maintenance
7. indirect maintenance expenses:
   - expenses related to the equipment malfunction,

- additional maintenance expenses and
- expenses for additional equipment break in.

Considering the significant strategic and tactical importance of maintenance, starting point for managing maintenance costs is a strategic management decisions that further define maintenance strategy and approves expenses for maintenance plans (budget), which is then further worked out on the tactical level (production manager, head of maintenance). In accordance with the verified maintenance expense plan, realization of maintenance activities commences as well as logistical support to continuous business processes.

On the basis of verified expense models and procedures for monitoring maintenance expenses, actual maintenance costs are monitored on operational level including their contribution to the manufacturing and operating costs.

Reports about incurred maintenance expenses are controlled on a tactical level, deviations of the costs from the plan are determined, followed by the analysis of the cause. Results of the maintenance cost analysis are corrective measures going in two directions:

- correction of the maintenance activities on the operational level and
- as the proposal for modifying maintenance strategy, if this requires decisions by the top-level management

3.2 Information system for managing maintenance economics

Managing maintenance expenses can be located in the framework of:

- IS for maintenance management or
- IS for cost management.

Based on the concept created by CIM Centre from the Mechanical Faculty in Kragujevac, managing maintenance costs is located within information system for maintenance management and there is also two-way relation to information system for managing costs. Of course, reverse relation also exists, database for managing costs provide certain data for managing maintenance costs.
Basic concept of the IS for maintenance management is based on the client/server architecture, which is very flexible and can satisfy the various existing and future needs of IS expansion.

Shared and relatively constant data related to the entire business system is placed into joint database and the second part of the data is placed into distributed databases.

If we observe the typical, medium size, industrial enterprise, in which the maintenance is a support process, information system development projects that improves maintenance economics has phases shown in table 2.

Table 2. Gantt chart of the activities for development and implementation of the IS for improving maintenance economics

Seq. num.	*Title*	*Time/quarter*									
		I	*II*	*III*	*IV*	*I*	*II*	*III*	*IV*	*I*	*II*
I	***Development of measurement methodology for monitoring and reporting on maintenance economics***										
II	***Development of procedures and instructions for securing quality in maintenance processes***										
III	***Development and implementation of module for managing maintenance economics***										
IV	***Integration of the maintenance economics module into the managing information system***										

If these project activities are analyzed from the aspect of engaging human, material and financial resources, following variants can be identified:

a) own development,

b) use of consulting services for certain phases of the project,

c) consulting services based on the principle of joint teamwork with the user and

d) "turnkey" solution consultant services.

If we observe module for managing maintenance economics, most organizations in its realization go through phases described in figure 5.

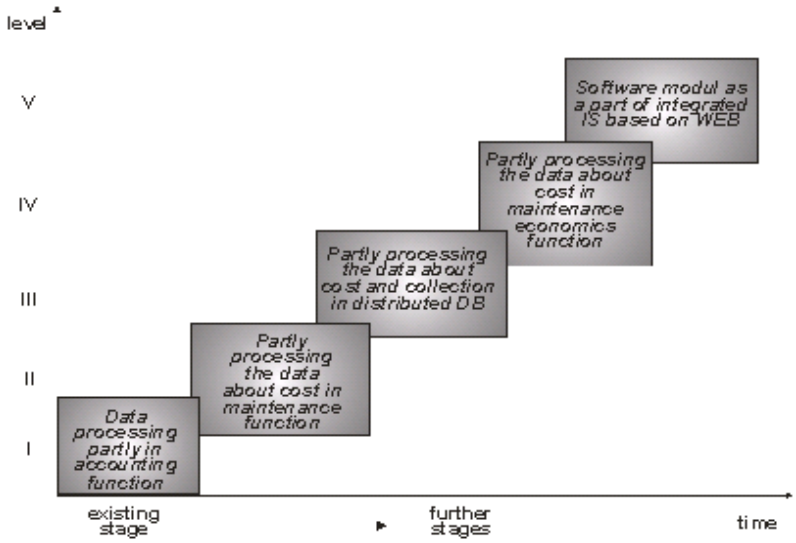
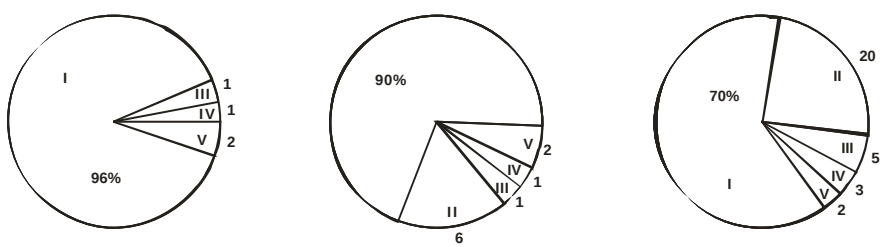


Figure 5. Information system for improving maintenance economics' development phases

Preliminary research of the authors point out the existing levels of information systems for improving maintenance economics, for small, medium and large organizations, as shown in figure 6.



a) "small" organizations ***b) "medium" organizations*** ***c) "big" organizations***

Figure 6. Condition of IS for improving maintenance economics' levels

Preliminary results show low entry-levels of information system development for improving maintenance economics. How to transition from this unsatisfactory state into the state where level V dominates and particularly, how to accomplish this in the conditions of deficit financial, human and infrastructural conditions? Answer to this question is not simple. Strategy is different for each organization. However, some joint elements of the strategy can be seen. These are:

- making efforts to create quality management system, which becomes a facilitator for organization's competitiveness, to incorporate the aspect of maintenance economics into the QMS procedures,
- decreasing costs of information and communication equipment and gradual investment in the IS project

for improving maintenance economics,

- capability of communication technology to network distant locations within organization and networking with the business environment,
- possibility for faster and cheaper development, implementation and IS maintenance by professional IT enterprises,
- possibility for object-oriented approach in the development of the software for quick upgrade and changes, caused by internal and external demands.

Through application of the original AS2 method developed in CIM Centre at the Mechanical Faculty in Kragujevac, logical database design was performed and development of the application software was started.

3.3 Model of the equipment maintenance process

In this section of the work, authors decided to present results of the modeling process and structure of the computer network in one construction company with physically separated primary production and workshop for maintenance and construction. Figure 7 shows second-level of process obtained through application of the SSA *(Structured System Analysis)* method, identifying three sub-processes of maintenance:

- *creation of the technologies and maintenance plans for equipment,*
- *manufacturing of the spare parts and equipment maintenance with use of work orders.*

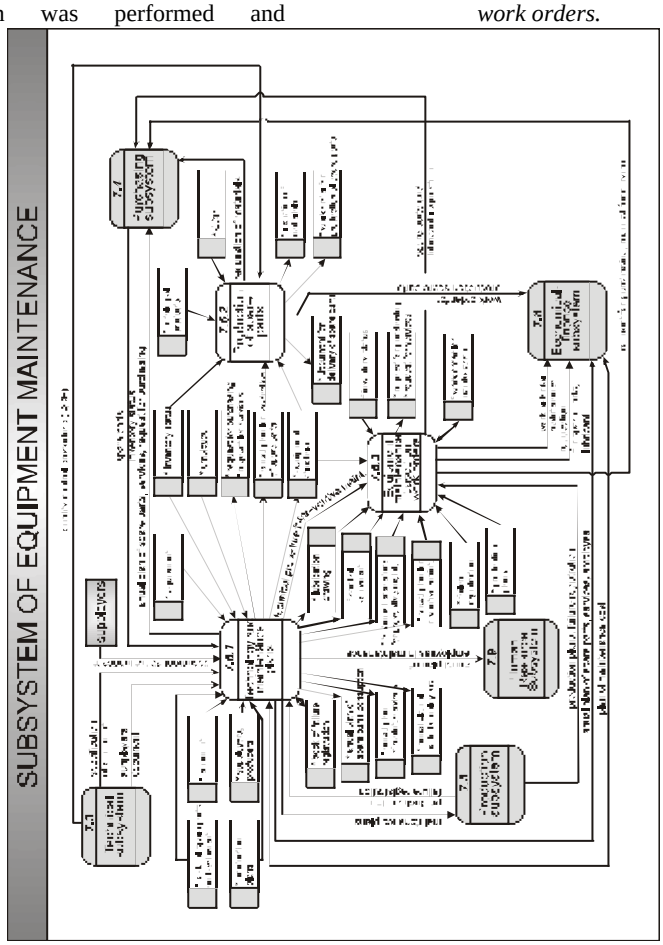


Figure 7. Model of process (DTP) for subsystem of eqipment maintenance

4. CONCLUSIONS

Based on the presented work, the following conclusions can be made:

- Definition of the new process metrics began with organizational objectives through organizational metrics/process arriving at process objectives, which have to be measurable and maintaining level of the achieved progress.
- Through use of management process algorithms, procedure for identifying existing processes has been determined, method for determining critical processes and measurement of critical processes based on the process characteristics.
- Application of the aforementioned quality metrics, enabled us to measure maintenance process improvements, which are 4.6% higher when compared to the quality process entry levels from 18 months ago.
- Efficient and effective management of maintenance economics cannot be accomplished without information system based on the application of modern information technology.
- Information system for managing maintenance economics must be based on expense model specific for each organization.
- Information system for managing maintenance economics must include strategic, tactical and operational aspects of decision-making within the domain of equipment maintenance.
- Information system concept for managing maintenance economics must be open and adaptable to grow with information system and included processes, facilitating completion of this information system after a few years.
- Measurement of the maintenance success rate uses large number of methods.
- Overcoming subjectivity in measurement is achieved by use of synthetic indicators (costs, production etc.)

  application of the value analysis methods has created the original system for evaluating maintenance efficiency, being tested in the mining industry, metallurgy industry, process technology and metal processing fields.

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