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Improving the Quality of Maintenance Processes by Using Information Technology

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Due to increased levels of automation and quality, production maintenance is becoming increasingly important and for some branches of industry, even indispensable.

Since the quality of the entire process is increasibly 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 paper.

This approach begins with organizational goals, quality objectives in particular. Then, maintenance processes and integrated information system structures are defined. Maintenance process quality and improvement processes are defined using a set of performance characteristic, with a special emphasis placed on the effectiveness and quality economics. The paper also presents the structure of the information system for improving maintenance economics as well as simulation software solution for integrating maintenance and production functions. Besides a theoretical analysis, the work also presents the results authors obtained by analyzing the food industry, metal processing industry and building materials industry.

Keywords: quality, maintenance process improvement, information technology, simulation, maintenance economics, maintenance effectiveness

0 INTRODUCTION

The acceleration of supply chain pace in which customer orders are initiated and finished products are delivered, is one of the basic problems manufacturers must compete with and overcome. The most universal challenge lies in handling operational, supply and demand exceptions, which leads to the apparently impossible mission of planning for the unplanned [1]. The speed at which a business system identifies these exceptions and react in order to reduce its negative impact on the overall system performance primarily depends on the responsiveness of implemented Information Technology solutions and their capability of handling the above three factors.

Maintenance means maintaining and *improving* the integrity of our production and quality systems through machines, processes, equipment and people who add value to our products and services, that is, the operators *and* the maintainers of our equipment [2].

Maintenance has one of the most important functions, which is looking after assets and keeping track of equipment in order to secure productivity, flexibility and quality. With a poor maintenance function a company will lose a lot of money due to lost production capacity, cost of keeping spare parts, quality deficiencies, damages for absent or late deliveries, etc [3]. Despite that, in many companies where maintenance is viewed as an operational expense to be minimized and not as an investment in continuous process improvement, maintenance practices decrease their competitiveness by reducing throughput, increasing inventory, and leading to poor due-date performance. The wrong approach to maintenance may result in a failure of a business. Management aware of this fact and able to use Productive Maintenance best practices is on the right path to prosperity [4].

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

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

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- improving maintenance processes quality.

The first way dominates because the total number of maintenance workers and the maintenance budget is up to 5% of the entire organization. Exceptions to this rule are maintenance in mines, metal processing enterprises and process industries, where these percentages are significantly higher.

In these conditions, a different approach to increase maintenance process quality is needed.

Simultaneously, principal paradigms in the field of maintenance are changing, starting with corrective maintenance, continuing through preventive maintenance and ending with an entirely productive maintenance [4]. In practice, organizations use some combination of the already mentioned maintenance concepts.

From the large number of papers from this field, the authors of this paper use concepts explained in papers which deal with maintenance management using a holistic approach, business processes, risks and the role of maintenance, the role of benchmarking in improving maintenance management, industrial systems maintenance modeling, scheduling of preventive activities in the actual production limitations, maintenance policies evaluation and the use of the AHP method for an efficient maintenance system. Also, the authors analyzed a large group of papers from the field of improving maintenance processes and the relationship between quality and maintenance. The authors use elements of the Japanese strategy and the role of TPM as well as analyze different aspects of maintenance quality, the relationship between maintenance processes and product quality and organization (QMS – Quality Management System) and wider (IMS – Integrated Management System). Quality is connected with maintenance (at low level) or incorporated in the maintenance process (at high level). It starts with quality goals, policies, strategy, procedures on tactical level and the performance of maintenance activities.

A large number of authors in referenced papers deal with effectiveness, maintenance effectiveness, holistic approach to effectiveness measuring, efficiency and the effectiveness of measuring maintenance performance, cost-benefit analysis, demands and challenges in measuring maintenance performance, multi-criteria, a hierarchical framework for measuring maintenance performance and the application of Balanced Score Cards (BSC) in measuring maintenance performance. This group of works also deals with the measurement and analysis of performance effectiveness and, above all, maintenance economics.

A general conclusion regarding areas for improvements of the overall maintenance function can be divided into four different areas: maintenance management, materials and spare parts management, controlling and reporting and information technology (IT) support [5]. Detailed solution areas on the way to effective maintenance are reviewed in Figure 1.

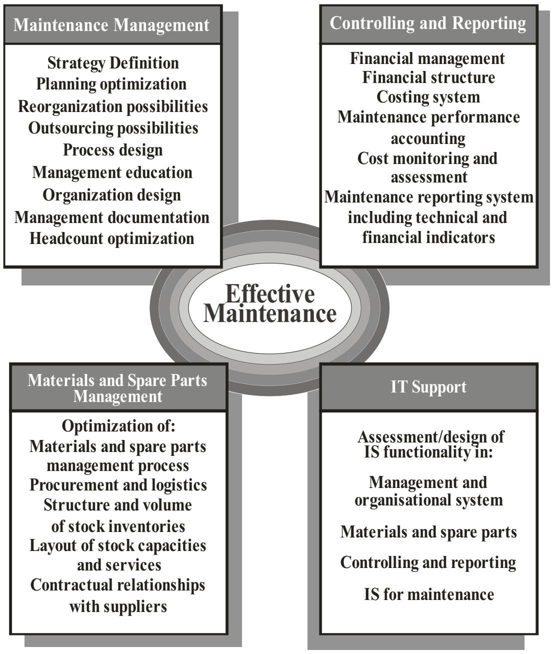


Fig. 1. *Solution areas on the way to effective maintenance*

If we observe the maintenance process quality (Q), we notice that it is most often defined by using suitable performance indicators. Used performances indicators are usually related to maintenance costs (independently or related with other expenses or income), maintenance efficiency and similarly. Apart from the quality as the main goal of maintenance, the 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 [6].

The purpose of this paper is to:

- present an empirical analysis of Productive Maintenance,
- introduce a maintenance process improvement approach,
- present design approach for the cost monitoring, assessment and reporting system for maintenance,
- defines IT environment promoting maintenance effectiveness and
- introduce simulation software capability for integration of maintenance and production functions.

In short, the scope of this work is maintenance process quality and opportunities for improving maintenance process quality through the application of information technologies. A significant number of authors have researched this field, starting with the capabilities of information technologies for monitoring, effective implementation and decision-making in the maintenance process. Quality was observed as the output characteristic of this maintenance process supported by the application of information technology. The authors of this paper present an alternative approach with its principal elements as follows:

- taking into account the organization's objectives and defining components of the process goals,
- after defining the maintenance process goals in the previous step, component objectives P, Q values are defined and F of the maintenance process,
- the maintenance process is modeled in such a way as to achieve these objectives through an application of various planning methods and process analysis (most often through effectiveness and maintenance costs),
- the application of the chosen information technologies results in the design of the software enabling maintenance processes improvement,
- in accordance with the new project solution, maintenance processes are designed in detail and applied in practice with continuing 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 the research and application of this concept in enterprises working in the field of food industry, construction and metal processing. Due to limited space, this work describes the third and the fourth activity of the proposed concept in detail.

1 MAINTENANCE PROCESS IMPROVEMENT APPROACH

1.1. 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 through the use of a benchmarking process as a well known and universal approach, we determine that the observed organization (O) significantly lags in quality levels compared with control sample organization (A), then continuous improvement concept will not be sufficient to close this "gap". A determined, planned and timely approach to reengineering process must be applied [6] to [8]. Both approaches are based on the use of a well-known Deming's PDCA (Plan, Do, Check, Act) cycle.

By using the process objective matrix [8] to [10], process characteristics are obtained, those that have process quality characteristics as well as those related to the effectiveness and efficiency of the process and the entire organization. An analysis of the process characteristics is conducted in the following phase and the characteristics that are determined to be successful by nature are determined. In this way, an answer to the second question is provided (Fig. 2).

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

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

We can conclude that the quality improvement process has four phases:

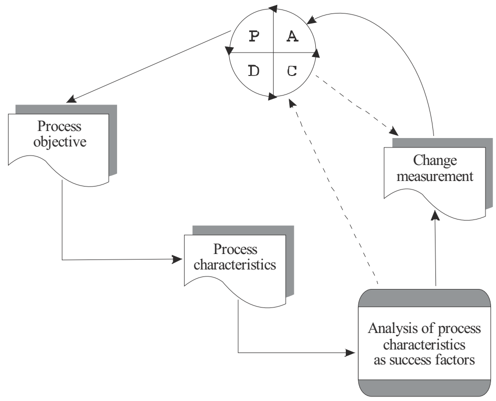


Fig. 2. *Process quality improvement procedure*

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 [6], [11] and [12].

The authors in this paper emphasize the design of the process changes aspect, which consists of sub-processes related as shown on the Fig. 3.

The designing of changes is accomplished in six steps (sub p-rocesses). 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).

The primary activities flow, depicted with a solid line in Fig. 3, indicates the primary order of activities and the secondary (dotted lines) the feedback of information and the correction of inputs for the following processes.

1.2. Measurement of the Critical Processes and Maintenance Process Metrics

1.2.1 Measurement of the Critical Processes

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

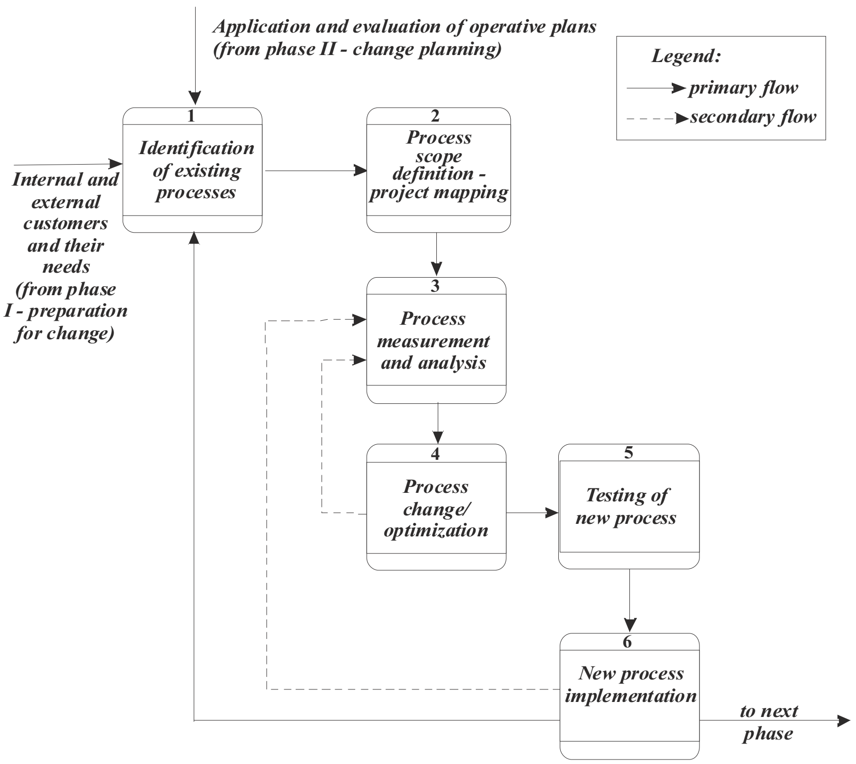


Fig. 3. *Steps for process changes design*

Process metrics can have various forms [8]. 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 by using various methods, of which the process of evaluation and benchmarking are the most frequently used.

Benchmarking outputs are various. These are primarily system comparisons and disparity against the sample organization. Then, proposals for improvements obtained through the research of the organization and based on the customer demands follow.

Process evaluation can be conducted in various ways, using several 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 (Table 1):

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 are obtained from financial plans, quarterly and biannual financial reports (created by the economic and finance departments, related to maintenance and delivered to the maintenance managers).

K3. Maintenance flexibility:

(*Σ delays time / Σ maintenance time)*.

K4. Operational readiness (*OG*) or Availability (*A*):

$$OG = \frac{Tur}{(Tur + Tuo)}$$

where *Tur* - denotes up-time and *Tuo* - denotes down-time, *A* = *Tur* in percentage of planned run time.

Data are obtained from the records of measuring and monitoring the 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.

Table 1. *Values of the maintenance quality characteristic*

K1 Completed	K2 Excess of the maintenance expenses	K3 [%]	K4 [%]	K5 Percentage increase [PO]	Mark (estimation)
0	< 1	100	100	> 50	10
1	1-5	100-150	90	40-50	9
2	5-10	150-200	80	30-40	8
3	10-15	200-250	70	25-30	7
5	15-20	250-300	60	20-25	6
10	20-25	300-350	50	15-20	5
15	25-30	350-400	40	10-15	4
20	30-40	400-450	30	5-10	3
25	40-50	450-500	20	1-5	2
30	> 50	>500	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	$VK = DO \cdot P$
Process objective (UP): $UP = \Sigma VK = 4.2$					

Data are obtained from the records of measuring and monitoring characteristics of: machinery and equipment maintenance, building maintenance, installation and infrastructure maintenance, which are delivered monthly to the head of maintenance by responsible personnel. The head of personnel calculates percentage increase over the previous period. The head of maintenance is responsible for monitoring and follow-up of the process' performance as well as personnel in other organizational units.

Table 1 is used to calculate the mark. A report on measurement and monitoring is delivered to the technical sector manager. An evaluation of the process performance is conducted quarterly, a good application of corrective or preventive measures as needed.

2 DESIGN OF THE COST MONITORING, ASSESSMENT AND REPORTING SYSTEM FOR MAINTENANCE

The maintenance costing system, as part of the maintenance financial structure, has inconsistent configuration. This is caused primarily by different business process management strategies applied to manage diverse structure and behavior of existing maintenance processes.

All outlined methodologies, regardless of the level of detail, can be improved in accordance with the following steps:

- design of financial management principles for maintenance,
- design of the financial structure,
- design of the costing system,
- design of performance accounting for maintenance,
- design of the cost monitoring and assessment system for maintenance and
- design of the reporting system (including technical and financial indicators) for maintenance.

The design of the cost monitoring and assessment system for maintenance and the design of the reporting system (including technical and financial indicators) can be implemented in different IT ambiance. In some organizations, maintenance function is responsible for the realization of this task, while in others the quality maintenance function is responsible and, in the most advanced, this is achieved automatically by using the Management Information System (MIS) module for managing all operational costs, together with maintenance costs [10] and [13].

In all cases, the main problems are initiated in the phase of cost system design because all the elements of expenses and losses that occur during the maintenance process are not incorporated in the analysis and modeling steps of software design.

This is the reason why authors at this point propose the following phases in the development of cost monitoring, assessment and reporting software solution for maintenance:

- Phase I: the development of the methodology for maintenance cost categorization, measuring, monitoring and reporting,
- Phase II: the creation of the procedures and instructions for ensuring quality in maintenance procedures, according to the ISO 9001:2000,
- Phase III: software solution development and integration with Maintenance Information System in accordance with the previous steps,
- Phase IV: creating ambiance of integrated Management and Maintenance Information System and
- Phase V: the development of simulation software solution capable for scheduling production and maintenance operations in ambiance of integrated Management and Maintenance Information System.

The majority of organizations in Serbia are currently in Phase I, only certified organizations (approximately 1450) are in Phase II. A considerably smaller number (less than 150) is in Phase III and there is even a smaller number of organizations currently in Phase IV (less than 50). There are no organizations belonging to Phase V and one of the aims of this paper is to emphasize the benefits caused by this IT ambiance.

2.1 A Conceptual Model for Maintenance Cost Monitoring, Assessment and Reporting

Maintenance expenses are a significant part of the production costs. This portion varies from 50% all the way up to 50% of production costs [9]. Therefore, it is clear that efficiency of the existing Maintenance Information System is reflected in maintenance cost monitoring, assessment and reporting. An issue with different ways of modeling the overall maintenance costs, including or excluding various constituent maintenance expenses, frequently arises during this software design process.

Having this in mind, the authors decided to use the conceptual modeling approach as a base for the analysis and modeling phase of the software design process [12].

Maintenance costs are divided into:

- direct and
- indirect costs.

Figure 4 shows basic conceptual model of maintenance cost monitoring, assessment and reporting software solution. Maintenance costs additionally can be divided into:

a) maintenance material costs,
b) maintenance spare parts costs,
c) service based investment maintenance costs,
d) current maintenance service costs,
e) costs for spare parts and materials warehousing,
f) costs of skilled labor performing existing maintenance activities (costs for direct and indirect labor on equipment maintenance),
g) indirect maintenance expences (expenses related to the equipment, breakdowns, aditional maintenanace and for aditional equipment failures).

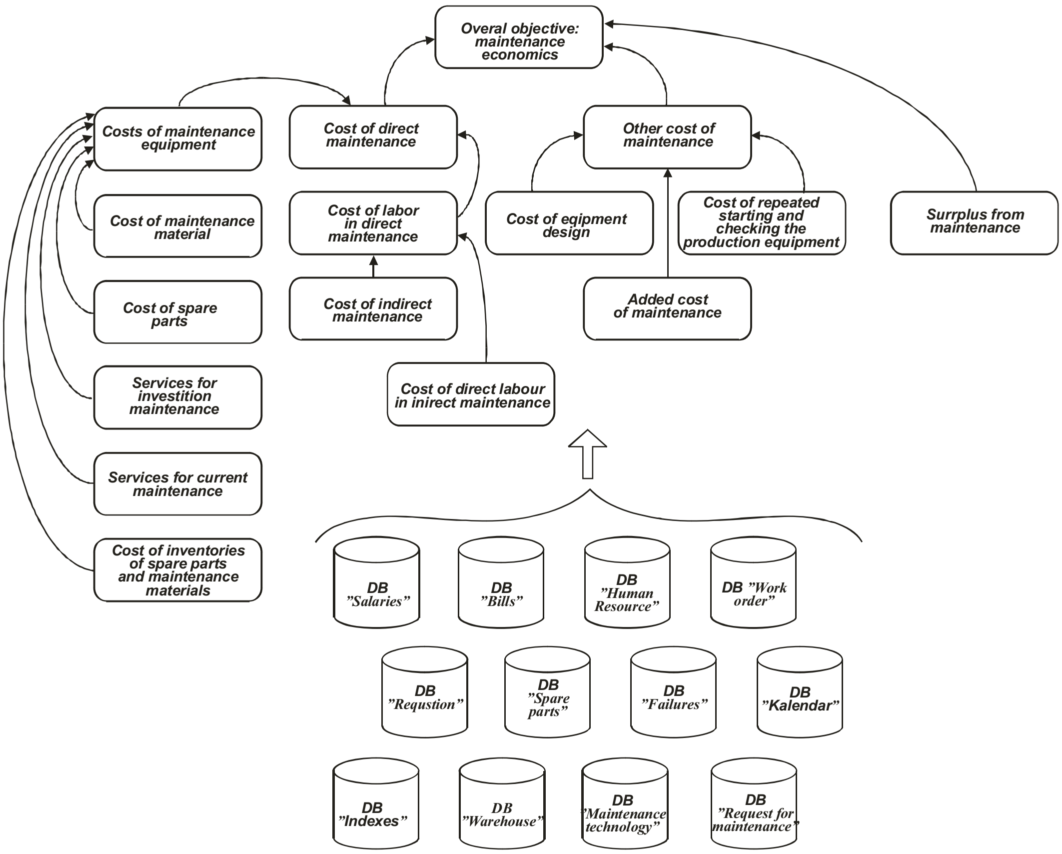


Fig. 4. *Basic conceptual model of maintenance cost monitoring, assessment and reporting software solution*

Considering the remarkable strategic and tactical importance of maintenance function, the starting point for managing maintenance costs are corporate strategic management decisions directing the maintenance strategy and approving 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, the realization of maintenance activities commences as well as the logistical support to continuous business processes.

On the basis of the verified expense models and procedures for monitoring maintenance expenses, the actual maintenance costs are monitored on the 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. The results of the maintenance cost analysis are corrective measures going in two directions:

- the 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.

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 [15], managing maintenance costs is located within the information system for maintenance management and there is also a two-way relation to information system for managing costs. Of course, a reverse relation also exists, database for managing costs provide certain data for managing maintenance costs.

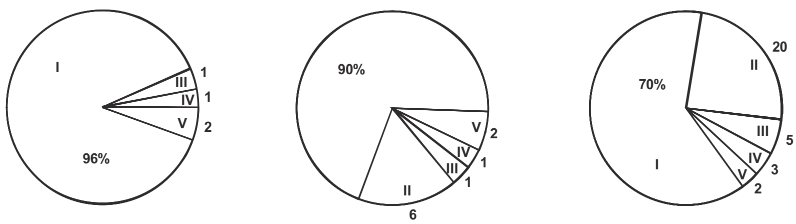
A basic concept of the IS for maintenance management is based on the client/server architecture, which is very flexible and can satisfy the various existing and future needs of IS expansion.

Shared and relatively constant data related to the entire business system is placed into a 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 maintenance is a support process, information system development projects that improve maintenance economics has phases shown in Table 2 [14].

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										



a) "small" organizations b) "medium" organizations c) "large" organizations

Fig. 5. *Condition of IS for improving maintenance economics' levels*

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

a) own development,
b) the 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 the module for managing maintenance economics, most organizations in its realization go through phases described in Fig. 5.

The preliminary research by the authors points out the existing levels of information systems for improving maintenance economics, for small, medium and large organizations, as shown in Fig. 6.

The preliminary results show low entry-levels of information system development for improving maintenance economics. How to transit from this unsatisfactory state into a state where phase V dominates and especially, how to accomplish this in the conditions of deficit financial, human and infrastructural conditions? The answer to this question is not simple. The strategy is different for each organization.

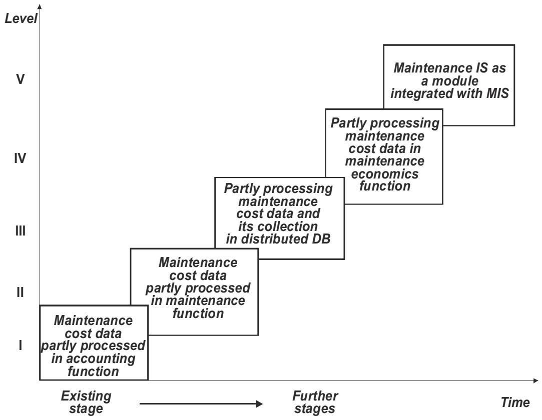


Fig. 6. *Phases of IT solutions development*

However, some common elements of the strategy can be pointed out:

- making efforts to create a quality management system, which becomes a facilitator for organization's competitiveness, in order to incorporate the aspect of maintenance economics into the QMS procedures,
- decreasing the costs of information and communication equipment and a gradual investment in the IS project for improving maintenance economics,
- the capability of communication technology to network distant locations within the organization and networking with the business environment,
- the possibility for faster and cheaper development, implementation and IS maintenance by professional IT enterprises,
- the possibility for object-oriented approach in the development of the software for a quick upgrade and changes caused by internal and external demands.
- through the application of the original AS2 method [15],
- in the phase V the organization is able to implement new techniques and software generation [15] to [20].

3 INTEGRATION OF PRODUCTION AND MAINTENANCE FUNCTIONS USING SIMULATION

One of the basic production and maintenance management problems is how to manage a business process and in a cost effective manner adapt to unavoidable changes dictated by the environment. The most universal challenge in this environment is handling primarily operational as well as supply, and demand exceptions which leads to the apparently impossible mission of planning for the unplanned. The speed at which managers identify these exceptions and react in order to reduce its negative impact on the production system performance primarily depends on, in the context of the paper, responsiveness of Management and Maintenance Information Systems and their capability of handling mentioned exceptions. The contemporary solution is integrating strategic and tactical decision making and, on production level, developing the capability for synchronization, modification and fine-tuning of production and maintenance plans and schedules as quickly as possible. The instrument of the mentioned integration is Discrete Event Simulation (DES) scheduling solution integrated with the Management and Maintenance Information System. The scheduling role of simulation in such a system is key owing largely to its ability to faithfully replicate the real production ambiance and quickly react to unpredictable exceptions in the field [20] to [23].

This causes problem in the design of corresponding simulation software models which will replicate complexity, enable evolution control of modeled system as well as synchronization of its own growth with named evolution. The simulation model designed by the methodology proposed here attempts to give an answer to this challenge: the integration of strategic and tactical decision making, developing the capability for production and maintenance plans and schedules reconfiguration and synchronization in a very short cycle as well as handling primarily, in accordance with purpose of the paper, operational exceptions.

This approach gives verbal and mathematical problem description, builds ontology of problem domain, uses Extended Petri Nets and event graphs as activity cycle diagrams as modeling tools in order to obtain a faithful model which can easily be replicated in object oriented class and object hierarchy. The proposed approach also gives emphasis to the unavoidability of knowledge transfer between business processes experts, software development experts, academic community research groups, as well as future DES users. Integration and overlapping of these fields of knowledge result in an object oriented application architecture fully consistent with the ontology derived from conceptual phase of design methodology. The proposed methodology enables a convergence of comprehensive but static knowledge of Management and Maintenance Information Systems in a dynamic simulation model in order to fully utilize its prediction power for an effective integration of strategic and tactical decision making of production and maintenance management. As a final development phase the authors propose creating such an IT environment which promotes effective maintenance. This fifth phase is the development of simulation software solution capable for scheduling production and maintenance operations in the ambiance of integrated Management and Maintenance Information System. The proposed change in IT technology enables production and maintenance department experts to work across functional boundaries as well as to identify problems, develop solutions, and execute plans. The proposed IT environment changes the functioning of a system by breaking down traditional barriers for the information flow, especially between maintenance and production departments. Simulation also supports improvement by looking from multiple perspectives at equipment operation and maintenance, includes maintenance in daily production tasks as well as long-term maintenance plans, and allows information sharing among different functional areas. Furthermore, simulation helps to improve the organization's capabilities by enhancing individuals' problem-solving skills and enabling learning across various functional areas.

Since a simulation study always crosses over functional domain borders, the potential users of simulation software come from several departments. According to the information flow between different functional areas of a manufacturing system presented in Figure 4., potential simulation software users are: capacity planners, schedulers, shop floor managers, maintenance managers, marketing and sales managers and engineering function managers. The mentioned users are at the same time also the suppliers of the information required to build, verify and validate the simulation model [20].

Simulation is a potential universal tool for the integration of management decisions at all levels of management hierarchy across company department borders. In proposed IT environment Maintenance Information System performs, as a minimum, work order management, planning function, scheduling function, equipment history accumulation, budget/cost function, labor resource management, spares management, and a reports function. To be effective, the Maintenance Information System must be fully implemented with complete and accurate equipment data, parts and materials data, and maintenance plans and procedures. With proposed IT solutions it is possible that the maintenance, production and engineering departments develop the spirit of teamwork and work towards Zero defects, Zero accidents and Zero breakdowns. The final goal is effective maintenance i.e. improving the state of maintenance and product quality as well as reducing waste and manufacturing costs.

Inputs for simulation experiment execution are primarily time based values describing job order (production) and work order (maintenance) information [23]. Simulation software presented in the paper is designed for production scheduling, however, because its structure is replication of production system, entering maintenance related data is trouble-free.

Timed losses related with maintenance function are as follows:

- nonscheduled time: time duration for which equipment is not scheduled to operate. This time may include holidays etc.,
- scheduled maintenance time: time spent for preventive maintenance,
- unscheduled maintenance time: time spent for breakdown,
- RD time: time spent for research and development purpose,
- engineering usage time: time spent for an engineering check up,
- setup and adjustment time: time spent for an operation setup and adjustment,
- WIP starvation time: time for which equipment is operating when there is no WIP to process,
- idle time without operator: time for which WIP is ready, however, there is no operator available [21],
- speed loss: time loss due to the equipment operating under standard speed, and
- quality loss: time for which the equipment is operating for unqualified products.

Realized simulation tools have a number of unique characteristics such as interactive Gantt chart display, specialized reports, integration with external data sources, specialized scheduling rules, concurrent graphical animation etc. The quality of the generated schedule is largely determined by the scheduling rules that are specified for selecting resources and operations. A complete set of rules must be incorporated into the simulation tool to support a specific range of given manufacturing identity.

The presented simulation software faithfully mimics structure and behavior of modeled systems registering all relevant data generated by simulation experiments. Simulation model gathers in time scale all the relevant events for every job and work order as well as the utilization of machines and other modeled resources in the system. The user obtains input, throughput and output time for every job/work order and, in one of the realized solutions with incorporated Just In Time strategy, calculated stock levels for material and finished product inventory.

The simulation experiment, in this case, covers a complete logistic chain connecting system communication with supplier and customer by optimized and integrated production and maintenance schedules in accordance with the determined goals and criterions. The implementation of realized software solutions can accelerate the flow of the right information, the quality and speed of decision making which results in increasing overall system performance. Fig. 8 presents Gantt charts obtained after the first and second simulation experiments for modeled system. The obtained schedule is optimized and throughput time is decreased by 18% for the first

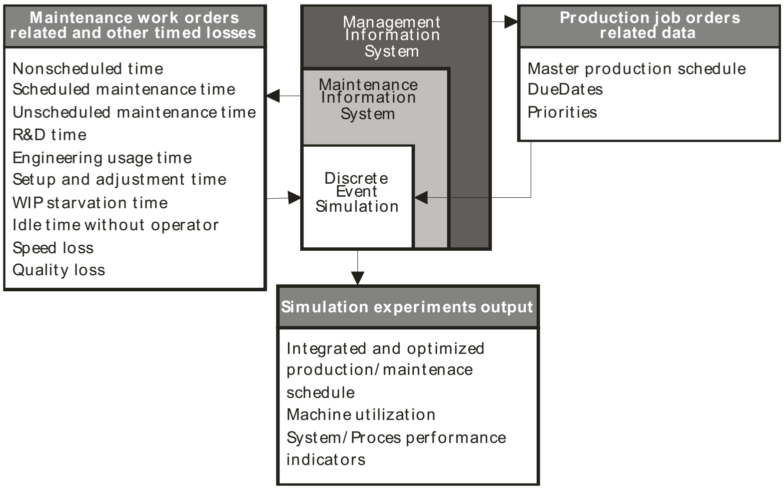


Fig. 7. *Proposed integrated structure of IT environment promising maintenance effectiveness*

system and 11% for the second (Fig. 9). Fig. 10 represents increased equipment utilization after schedule optimization.

4 CONCLUSIONS

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

- The 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 the level of the achieved progress.
- Through the use of management process algorithms, the procedure for identifying existing processes has been determined, the method for determining critical processes and the measurement of critical processes based on the process characteristics is based.
- The 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 an information system based on the application of modern information technology.
- The information system for managing maintenance economics must be based on expense model specific to each organization.
- The information system for managing maintenance economics must include strategic, tactical and operational aspects of decision making within the domain of equipment maintenance.
- The information system concept for managing maintenance economics must be open and adaptable to grow with the information system and included processes, facilitating completion of this information system after a few years.

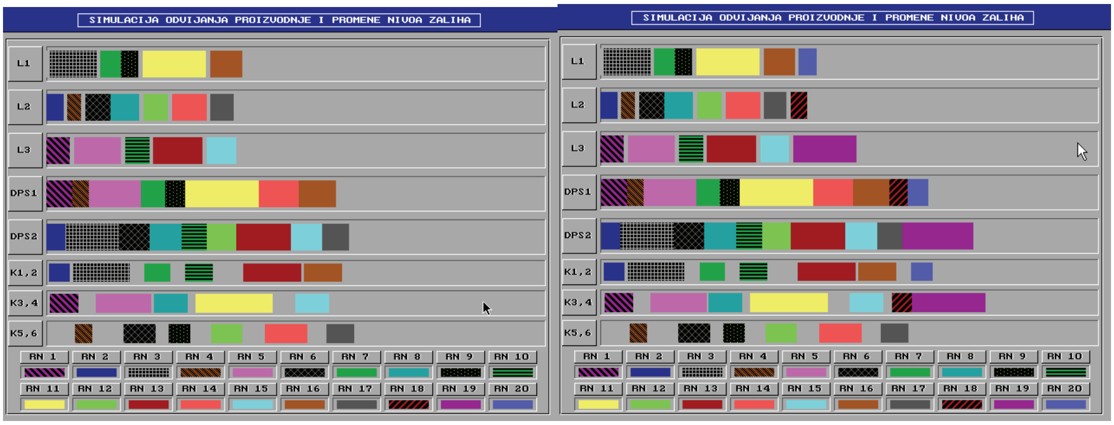


Fig. 8. *Gantt charts for production (left) and for production and maintenance (right)*

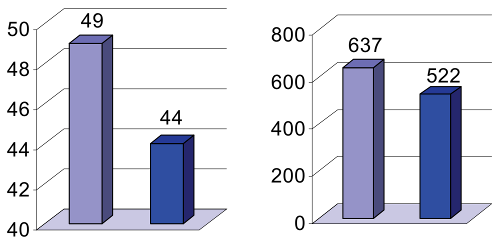


Fig. 9. *Reduced throughput times for modeled system*

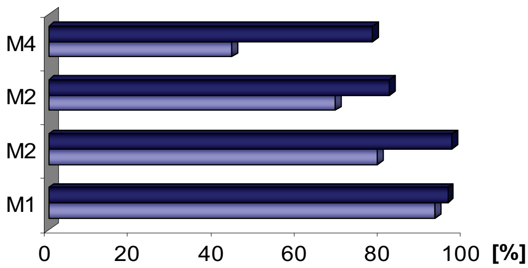


Fig. 10. *Increased work centers utilization*

- The measurement of the maintenance success rate uses a large number of methods.
- Overcoming subjectivity in measurement is achieved by using synthetic indicators (costs, production etc.).
- The 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.
- Simulation software integrated with Management and Maintenance Information System is a powerful tool for the integration of production and maintenance functions.

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