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A CYBERNETIC MODEL OF MAINTENANCE MANAGEMENT

by

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Abstract

Extremely high costs, very low productivity and extraordinary technical demands imposed by modern equipment have made maintenance management one of the last frontiers where considerable cost-saving and potential improvements can he achieved. Maintenance management is one area of industrial activity in which the gap between theory and practice is extremely wide. This Paper examines practical and theoretical problems of modern maintenance management. An innovative model of integrated maintenance management system, and cybernetic model of maintenance management are proposed and described, and future directions in the field are discussed.

1. Introduction

During the last twenty years, industrial management has become increasingly aware of the significant impact of maintenance operations on production and manufacturing costs. Constantly rising costs, low productivity and low efficiency of maintenance operations make maintenance management one of the most important areas of industrial activity. The need for considerable improvement in maintenance management has stimulated active theoretical interest. Undoubtedly, this interest has been provoked by extremely high costs and extraordinary technical requirements imposed by modern equipment; eg. airplanes, military systems, computers and electronic and technological equipment in industry. In many cases, this interest has led to the development of maintenance policies and models that possess theoretical novelty. The utilization of a wide range of mathematics, operations research techniques and the potential of extensive practical application have given rise to numerous maintenance models (.Langseth, H and B H Lindqvist. 2002). However, the analysis of the literature reveals that these models are rarely used in industry.

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Plant,maintenance management is one area of industrial organization in which the gap between theory and practice is extremely wide. While a broad range of mathematical techniques has been developed to aid in solving maintenance problems, very few maintenance decision-makers use these techniques in practice, (Turbam,1967.)

An examination of two bodies of literature (functional and theoretical) gives evidence that this gap still remains if, indeed, it is not widening. Theoreticians and practitioners in the maintenance area continue to speak in "different languages". In addition, different interests are perceived by theoreticians and practitioners. The theoreticians, on one hand, mainly concentrate (with some exceptions) on such problems as the deterioration of one or two parts (units) inspection, replacement and repairmen processes. This, to some degree, maybe explained by the necessity to select model formulations which are mathematically tractable or, at least, can yield to some manipulations. The practitioners, on the other hand, faced with intricate complexity and interdependency of maintenance issues, are interested in finding solutions to the multi- machine and multi-repairman maintenance problems.

Industrial enterprises exist in order to make profit and maintenance departments must contribute to that objective. Maintenance, with its high cost and low efficiency, became one of the last cost saving frontiers of management because productivity in manufacturing processes seems to be progressively approaching its hyperbolic growth limit. Maintenance costs are rising at about 15 percent per year. The rate of increase of maintenance costs is 30 percent greater than the comparable increase in production costs (Stauart, 1974). Higher rates of cost increase were found in an in-depth survey taken at maintenance management seminars attended by 3,500 plant engineers and maintenance supervisors from 2,000 different companies. This survey

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indicated a 28 percent annual increase in average maintenance cost during 1970-1975 (Joul, 1977).

The scope and magnitude of maintenance expenses may be illustrated by examples of industrially developed countries. According to Joul (1977), several years ago, an estimated 25 billion dollars were spent on maintenance in American industry. At the present time, these expenses are estimated to be closer to 35 billion dollars.

Existing data provides impressive indicators about the magnitude and importance of maintenance. The average maintenance expenses, in relation to the volume of sales, vary from one percent in British shipbuilding and marine engineering industry to six percent in chemical and allied product industry, (British Ministry of Technology, 1979). Similar results are also found in the USA where average maintenance expenses make up from 1.3 percent of total sales volume in shoe manufacturing to 6.8 percent in the chemical industry, (Newbrough, 1967). The ratio of total plant employees to maintenance employees averaged 5-to- 1 in British chemical and allied products industry and from 13-to-1 and 3.6-to-1 in some American industries and enterprises.

It is necessary to stress that maintenance management is more problematic in developing countries like Sri Lanka. Very often the new industrial plants and facilities are built and utilized without having an adequate maintenance system. The situation may be further aggravated by the considerable age and poor condition of much of the already existing plants. The deterioration of facilities is also due to the lack of attention from management and administration, which give a very low priority and status to the maintenance function. As a result of this, the maintenance system in these countries suffer from a number of basic deficiencies: large scattering of inadequate repair capacities, scarce work force, poor technical and technological base, less than up-to-date repair methods, low level of specialization and absence of mechanization of time-consuming maintenance operations, and poor supply of spare parts.

The high costs of maintenance are caused by the complexity and difficulties of maintenance operations. Maintenance operations are similar to those of intermittent, job shop, individual and, in some cases, batch-type of production. Nevertheless, maintenance management (planning, controlling, scheduling, administering) is sometimes more complex than the main production.

The purpose of this Paper is (1) to examine the practice and theory of maintenance management; (2) to introduce and describe an Integrated Maintenance Management System; (3) to propose and discuss a cybernetic model of maintenance management process; and (4) to outline potential future research in maintenance management.

2. Theory and Practice of Maintenance Management

An examination of the existing state-of-the-art in maintenance management shows that theory and practice are largely independent. On the theoretical side, there are a large number of maintenance models dealing with specific and narrow problems based on mathematically tractable formulations. The nature of theoretical models is mainly academic and only a few applications are reported in the literature. In addition, these models are rarely followed up or examined in comparative studies, and generalized formulations are usually absent. On the other side, decision-making methods used in maintenance practice are not comparable (with a few exceptions)to those proposed in theoretical models.

Before proceeding with a more detailed examination of the gap between theory and practice, it is useful to consider a classification of maintenance management problems. Table I includes a list of thirteen problems, as given by Jardine (1983).

This list of maintenance problems (far from being exhaustive), has a strong appeal to both practitioners and researchers. However, the methods of solution and the level of sophistication vary considerably in practice and theory. Some of the above problems are attractive to researchers, because of the possibility of using mathematical optimization and modelling processes. The analysis of the literature indicates that mathematical maintenance models are concentrated mainly on methods to solve problems 1, 2, 5, 6 ,9, 13, 16, 18. Some of the maintenance models are designed to examine problems 3, 11, 12 and 13. Some of the problems listed are also of great interest to maintenance managers. However, in maintenance practice the need exists to deal with these problems, not independently, but in their totality and interdependency. Practical considerations and limited resources force maintenance managers to combine these specific sub- problems into large maintenance problems (issues) and to seek satisfying and acceptable decisions instead of optimizing decisions. The maintenance techniques vary from plant to plant, from simple methods (charts, rules, graphs, schedules) to the complex computerized systems involving short-term work-programs, preventive maintenance and major PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) planning projects.The examination of maintenance practice and functional literature shows that sophisticated mathematical maintenance models have not yet been effectively applied to real-life maintenance problems, and, if they have, there is a lack of convincing case-study literature on the subject.

Table I - Specific problems of maintenance management

1. Inspection frequencies
2. Depth of inspection
3. Overhaul (corrective) intervals, i.e. part of a preventive maintenance policy
4. Whether or not to do repairs, i.e. a breakdown policy or not
5. Replacement rules for components
6. Replacement rules for capital equipment-perhaps taking account of technological change
7. Whether or not an equipment modification should be made
8. Reliability considerations
9. Maintenance crew sites
10. Composition of machines in a workshop
11. Spares provisioning rules
12. Sequence rules for jobs requiring some form of maintenance effort
13. Scheduling start times for constituent jobs of a maintenance project

Sound maintenance management practice requires managers to solve many complex problems that do not appeal to researchers, or are not easily quantifiable. Table 2 presents a list of some maintenance management problems faced in practice which are more complex and more general than those listed in Table 1. These problems have not, to our knowledge, been modelled. After two decades of development of maintenance models, it is noted that procedure that is gradually being considered by engineers as a method of assisting them in their maintenance decisions is that of having a mathematical model built which can be used to resolve, in a quantitative manner, the conflicting features of the situation.

Table 2 - Problems in Maintenance management practice

Maintenance organization
1. Rationalization of interdepartmental relations
2. Decentralized vs. centralized vs. combined forms of maintenance
3. In-house vs. contracted maintenance

Maintenance planning and control
4. Long-range vs. short-range maintenance planning
5. Scheduling and sequencing of multi-activity in the maintenance departments
6. Facility planning for maintenance operations

Maintenance performance monitoring
7. Measurement and management of workload
8. Adequacy of cost and performance
9. Measuring and improving labour usage
10. Evaluation criteria for inter- and intra-analysis of maintenance effectiveness

"Human Aspect" of Maintenance Management
11. Personnel management, training and development
12. Prestige and status of maintenance employees
13. Payment, incentives and merit rating
14. Problems of maintenance job enrichment

Existing empirical data shows that this procedure is continuing to develop very slowly. At the present time, only a few known studies examined the application of operations research techniques in industry. With the exception of Turban's (1967), research, the above-mentioned studies were primarily designed to investigate the application of OR techniques in American industry and, therefore, the information on maintenance is only a sub-product of these studies. Although there is not much information on practical utilization of mathematical and operations research models in maintenance management, some general directions and trends can be identified.

In the past, the average percentage of respondents indicating use of OR generally more than doubled. At the same time, the corresponding increase in maintenance area was only 38 percent, or, in other words, practical introduction of operations research techniques related to maintenance was 2.7 times slower than implementation of these techniques generally. Out of eleven different areas of industrial activity, maintenance ranked 7-8 in studies by Hovey and Wagner (1958), and by Schumacher and Smith (1965). Ledbetter and Cox (1977), have found that maintenance management had the lowest level of operations research models out of fifteen areas of industrial activity.

Interpreting the low use of OR techniques in maintenance, Hovey and Wagner (1958), and Turban (1967), have concluded that this does not indicate low potential for OR application in maintenance, but that it is a broad, untapped area for research.

Agreeing with this statement, we have to note that one of the reasons for the low utilization of mathematical and OR models is the problem of application of these models to maintenance practice. An analysis of the maintenance models, reported in the literature, brings us to the following conclusions.

First, most of the models are dealing with deterioration, inspection, replacement and repair problems of one-component (unit) or one-machine systems, which, from a practical point of view, have little utility. Second, there exists an over-emphasis on replacement and/or inspection policies. Very often repair operations are not considered or they are given a simplified role in maintenance management models. Third, most of the models and studies deal with the stochastic nature of failure distribution, but very few with stochastic repair operations. Fourth, there are only a few models or studies of multi-part, multi-echelon, and multi-machine interaction maintenance problems. However, most of these models also assume homogeneous (identical equipment) population. And fifth, there are many behavioural problems associated with implementing theoretical maintenance models. Maintenance managers feel threatened by the complexity of these models and resist changes that the implementation of these models may bring.

The area of multi-element interactive maintenance systems (as opposed to replacement and/or inspection problems of single unit systems) is perhaps the most difficult to handle mathematically, especially when the interactions occur because of stochastic dependence between the components. By employing heuristics and approximate computations, it is possible to build simple integrated maintenance models which can be easily solved and "sold" to maintenance practitioners.

3. Maintenance Management: A Systems Approach

The existing problems in maintenance are caused by an absence of long-range policies and a "piecemeal" approach to maintenance problems in practice and especially in theory of maintenance management. There is a need for a systematic and holistic approach towards maintenance management. At the present time, we may distinguish between three systems approaches to maintenance management, which are different in scope and purpose:

1. Integrated Maintenance Management Models.
2. Terotechnology.
3. Integrated Maintenance Management System.

3.1 Integrated Maintenance Management Models

Integrated Maintenance Management Models (IMMM) may be viewed as models designed to deal with a maintenance sub-system (a specific group of equipment, specific function of maintenance, a particular production-department area, or a combination of the above, etc.) which is a part of a larger maintenance system. Thus, IMMM may be defined as a model (Sub-System) combining two or more maintenance activities and problems. For instance, Bovaird's model (Bovaird 1961), integrates maintenance workforce, periodic inspection policy, and preventive inspection policy; Jensen's model, (Jensen 1975), integrates ORLA (optimum repair level analysis) with LSA (logistics support analysis) and LCC (life cycle cost); and Ladany's model, (Ladany 1975), simultaneously determines the size of maintenance personnel and preventive maintenance policy for a homogeneous group of machines.

The IMMM approach has several advantages in comparison to mathematical and operations research maintenance models. First, the assumptions of IMMM are closer to real-life industrial conditions; second, it allows one to deal with optimization of several activities simultaneously; third, most of IMMM models are simple in construction and therefore easily understood by practitioners; and fourth, a large amount of computational work can be computerized and special computer packages may be developed for IMMM.

Among the major shortcomings of current IMMM, it should be noted that these models solve only a small part or deal with only a small section of the total maintenance system. Also, these models are mostly based on homogeneous (identical equipment) populations. Therefore, in the future, the development of integrated maintenance management models should move towards incorporating more types of activities, non-identical groups of equipment, different types of maintenance policies, heterogeneous maintenance, and so on.

3.2 Terotechnology

Terotechnology is a different approach towards maintenance management. Under this method proposed by British researchers, the equipment life cycle is viewed as a longitudinal system approach. Terotechnology consists of different activities, including the maintenance function.

Terotechnology is a combination of management, financial, engineering, and other practices applied to physical assets in pursuit of economic life-cycle costs; it is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification and replacement, and with feedback of information on design, performance and costs, (Corder 1976.)

The word "terotechnology" itself stems from the Greek work terein-"to look after"-"to guard over"-"to take care of". The terotechnology process is summarized in Figure 1.

Terotechnology, which is concerned with the total life cost of the equipment, is based on trade-off notions. For instance, lower investment cost into equipment can be offset by higher operating and maintenance costs and vice versa. The main idea in terotechnology is that there should be communication between various stages of the equipment life-cycle by providing a formal and consistent flow of information around the system. As seen from Figure 1, feedback information about equipment comes to the design stage from all five phases of installation, commissioning, operation, maintenance, and replacement. Under the terotechnology concept, maintenance is perceived as a part of overall resource management and not as a simple repair function. It is also expected that maintenance managers will be involved in the various phases of the life cycle of machinery and especially in the design phase.

Husband (1976), views the term terotechnology as inappropriate and confusing. He notes that this concept has not so far been enthusiastically received by industrial managers. There is a suspicion that it is simply a new word to describe old ideas. Nevertheless, several successful applications of the terotechnology approach in the British Steel Corporation, British Rails, and Italian and German steel companies are reported in the literature. Though the maintenance function is one of the components of terotechnology, it has so far received in the literature greater attention than any other phase.

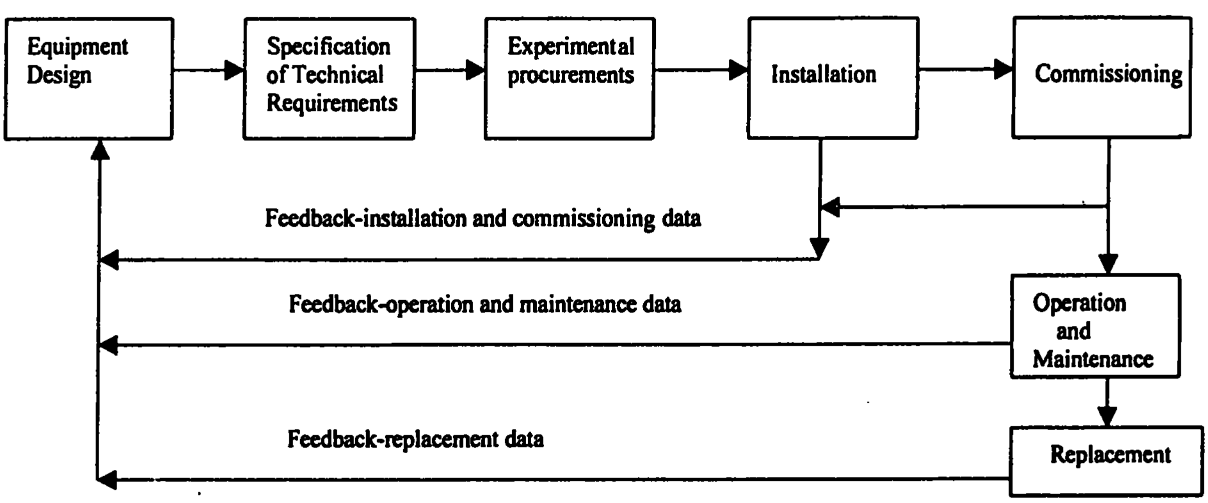


Figure 1: The terotechnology process

Generally, terotechnology may be viewed as a formal approach of an integrated nature to resource management, of which maintenance is one of the subsystems. The concept of terotechnology is applicable to different types (flow shop and job shop) and sizes (small, medium and large) of production systems. There exists a similarity between terotechnology, logistics management and life-cycle costing, which are widely used in the USA.

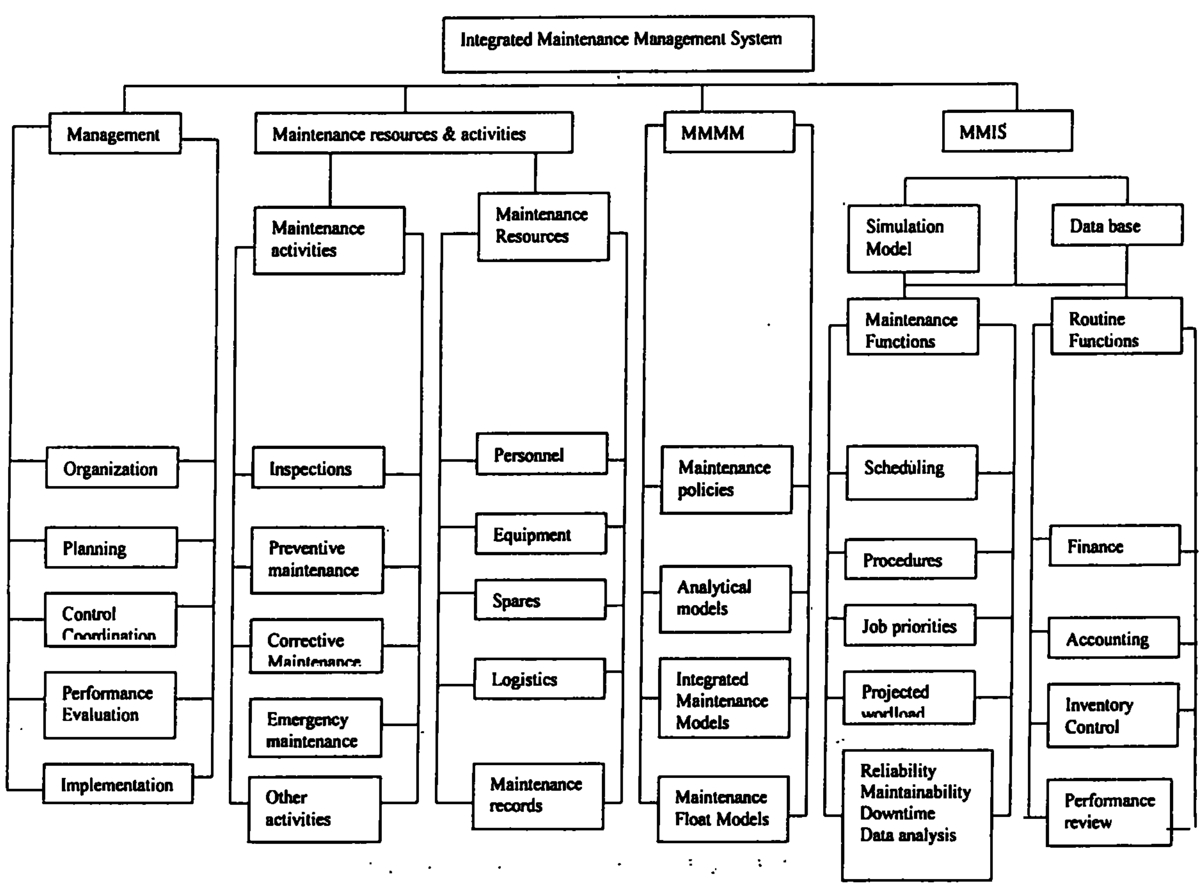
The maintenance function can be instrumental in developing maintenance procedures and forms at the design stage. However, it is necessary to understand that the terotechnology concept provides a narrow approach to the maintenance function: first, it deals with the external effect of maintenance on the life-cycle costs of the equipment without considering the improvement of the maintenance operations; and second, it offers a narrow (subsystem) approach to dealing only with a specific type or group of equipment. It does not integrate different types of equipment, various organizational forms of maintenance, and so on.

Because the equipment is usually manufactured by outside producers, it is doubtful that the maintenance manager will generally affect the major design and production decisions.

3.3 Integrated Maintenance Management System

The discussions of Integrated Maintenance Management Models and the Terotechnology concept illustrate the shortcomings of modern maintenance organization caused by partial and non-integrated treatment of maintenance problems. The existing deficiencies also indicate the need for a larger framework, which will allow us to conceptualize the interrelationships among complex phenomena of the maintenance organization and to integrate them into a systematic whole. The Integrated Maintenance Management System (IMMS) may be defined as an array of interrelated components designed to maintain the equipment of the enterprise in good working condition. IMMS provides a complex of subsystems and elements, ideas, principles, arranged in a rational interdependence in the coherent whole of the maintenance system. The additional value of applying systems theory to the maintenance area is that it provides a mode for integrating much, if not all, of the knowledge in the field. It is a new way of thinking or restructuring the accumulated knowledge in a discipline. The failure to think in systemic terms and to apply a systems approach is evidenced in the existing practice and literature of maintenance management. The IMMS is illustrated in Figure 2(a).

Figure 2(a): Integrated Maintenance Management System



The IMMS consists of four subsystems: (i) management; (ii) maintenance activities and resources; (iii) maintenance management models; (iv) the maintenance management information system. The size constraints of this Paper limit us to a general discussion of each subsystem.

Maintenance management includes, together with the traditional management functions of organization, planning, and control, such functions as performance evaluation and implementation. Unlike the production function, where a tangible and measurable product is available for sale, and for which cost and profit per unit can be accurately calculated, the performance of the maintenance work cannot be measured in this manner. The low status of maintenance organization, coupled with assessment problems of maintenance efficiency, requires treating performance evaluation as an independent management function. The implementation function is also treated as a separate managerial subsystem because the introduction of maintenance models and policies is a very complex process, requiring the highest level of coordination between the production and maintenance departments.

Maintenance Resource and Activities include two interrelated subsystems: Maintenance Resources and Maintenance Activities. Maintenance resources, which, to a considerable degree, predetermine the type of maintenance the company is able to undertake, include maintenance personnel, technological and control equipment to be utilized in maintenance operations and the availability of spare parts and components. In addition, it also provides maintenance logistics and records. Maintenance activities consist of different types of maintenance operations: inspections, preventive maintenance, corrective maintenance, and so on.

The Mathematical Maintenance Management Models (MMMM) subsystem consists of four groups of models different in nature and purpose. Maintenance policies can be viewed as a set of heuristics; the application of which gives a satisfying result and provides a simplified method of conducting maintenance operations. Analytical maintenance management models, based on classical mathematical optimization and operations research techniques, usually allow us to find the optimal solution to maintenance problems of one- or two-unit (component) systems. Integrated maintenance models were discussed earlier in this paper. The last group of models is maintenance float models, which are still in a stage of development. These models deal with a flow of failed machines from an integrated group of operational machines to maintenance, and then with repaired machines from maintenance back to production operations. Maintenance float models are based on the concepts of inventory and queuing theories.

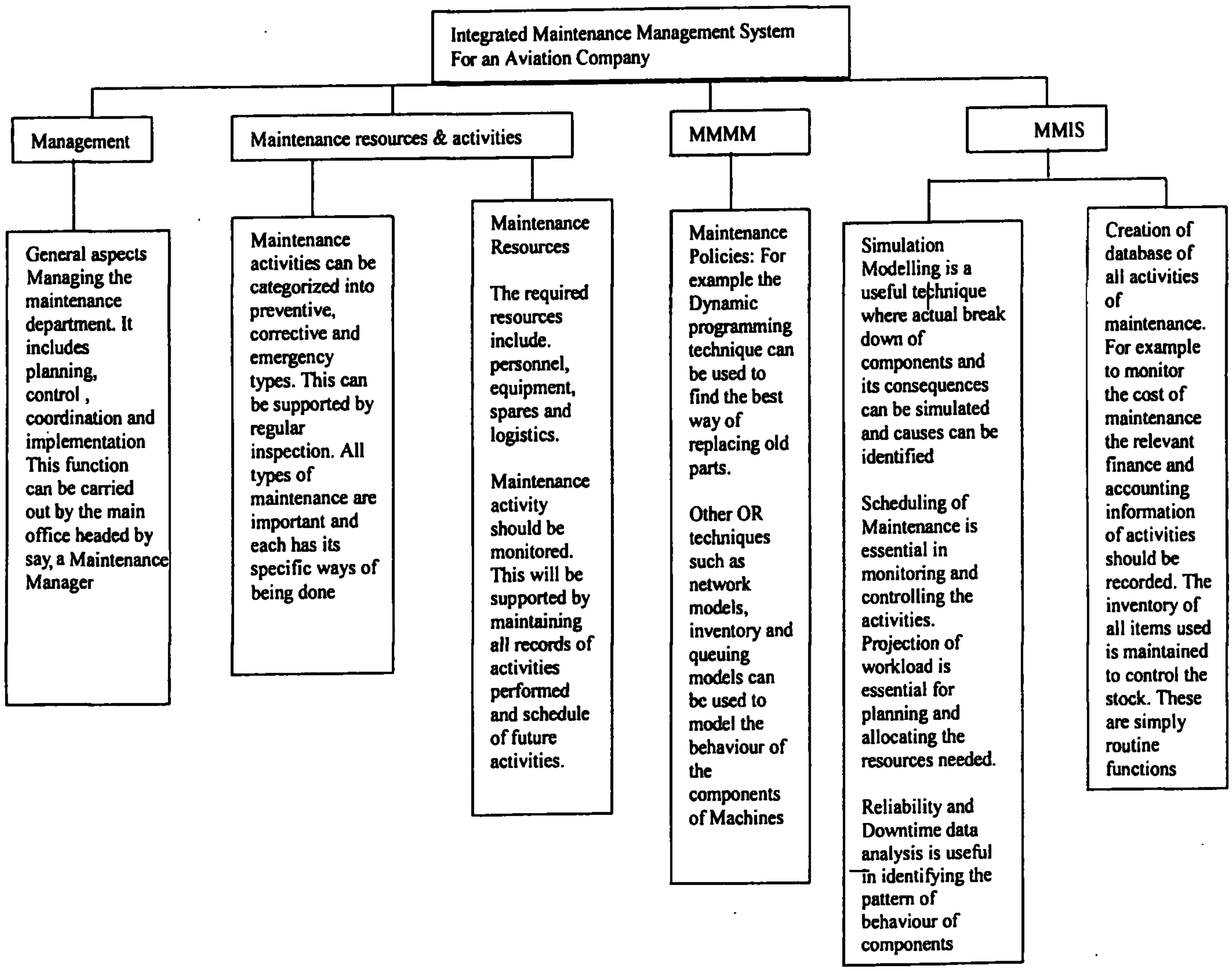
Maintenance Management Information System (MMIS) is the fourth subsystem of IMMS. MMIS includes the following four elements (subsystems): (i) Simulation models, (ii) Data base, (iii) Maintenance functions, and (iv) Routine functions. Simulation is viewed in the context of MMIS as a computerized experimentation with mathematical, logical and functional models describing the behaviour of a part of the whole maintenance system over extended periods of real time. The maintenance data, which is a part of a total organizational data base, should contain all necessary and pertinent information for effective maintenance management. The third element of MMIS is Maintenance Functions, which include maintenance "software": scheduling procedures, job priorities, projected workloads, reliability, maintainability and downtime analysis. The last element of the MMIS is *Routine Function*, which includes finance, accounting, inventory control and performance review functions. The main purpose of these functions is to serve as a medium for managerial control of maintenance operations by assembling the necessary data and providing feedback in the form of various computerized reports. Thus, implementation of MMIS, similar to the one proposed in this paper, will provide the maintenance manager not only with information about the current state of the maintenance system but also with the best possible alternatives for future actions to be chosen in terms of company objectives and policies. Specific instance of implementation of MMIS is given in figure 2(b).

3.4 Cybernetic Model of Maintenance Management Process

It is understood that IMMS, in its turn, is a part of a total management system and as such it becomes integrated with general management in a more productive way than present practice evidences. The IMMS is viewed here primarily as a conceptual framework which may help maintenance managers to improve the effectiveness and efficiency of maintenance operations. The systems approach to maintenance management can be operationalized by a cybernetic model of maintenance management process, as shown in Figure 3.

In the first block, total maintenance commitment should be established, and the maintenance resources (block 3) are allocated within the established commitment to maintenance. Block 2 deals with long-range maintenance strategy development. In block 5, the maintenance structure is completed. There is also a linkage between Blocks 3 and 5 through Block 4, where operational strategy and structure relationships are adjusted. This relationship not only describes the

Figure 2(b): Integrated Maintenance Management System



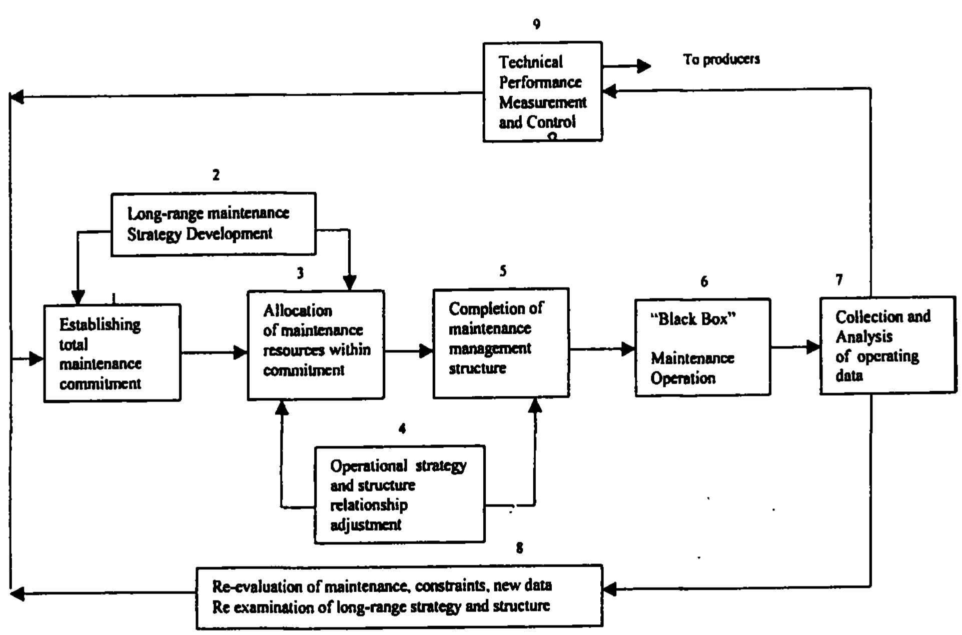


Figure 3: Cybernetic Model of Maintenance Management

modern interpretation of interdependency between strategy and structure, but also reflects the specifics of maintenance, when, for example, in case of emergency or unexpected plant shutdown, a flexible adjustment of strategy and structure is required. Block 6 is the traditional black (transformation) box, where maintenance operations are conducted. Block 7 is designated for the collection and analysis of operating data. The system is closed with two feedback Blocks 8 and 9. Using the operating data from maintenance operations, re—evaluation of assumptions, constraints and new data, together with reexamination of strategy and structure, is conducted in Block 8. The second feedback mechanism (Block 9) not only allows for the adjustment of the maintenance system, but also permits transfer to the producers the information gathered in appraising performance and control of the specific equipment and its components.

4. Conclusions

Our examination of the literature in the area of maintenance management, published in the past, shows evidence that there exists an extremely wide gap between the theory and practice of maintenance. Theoreticians and practitioners of maintenance continue to speak in "different languages" and perceive different interests. The existing empirical studies show that the application of mathematical methods and OR techniques is at the lowest level, as compared to other areas of industrial activity. There is almost no information about specific mathematical model or OR technique utilization in particular areas of maintenance management. Analysis of planning and scheduling practices shows that only a few companies have some kind of planning for one-year periods. Long-range and medium-range planning, as such, are not conducted. There is a large number of maintenance models in the literature based on mathematical optimization and OR techniques, as a result of different assumptions about the state of technical systems, time-to-failure distributions, maintenance policies, and so on. It should also be noted that very few, if any, practical applications of theoretical maintenance models are reported. It is also found that many assumptions of these models are often not warranted.

As a result of existing deficiencies, the cost of maintaining equipment in good working condition is very high and maintenance operations exhibit very low productivity and low efficiency. The present attempts to deal with maintenance through integrated maintenance management models and a terotechnology approach are incomplete and provide only partial solutions to the maintenance problems. In order for theory of maintenance to progress and radically improve the practice of maintenance, it is necessary that the present state-of-the-art in maintenance be looked at critically and integrated. The task of future research is to analyse and develop premises that will help in bridging the enormous gap between the theory and practice of maintenance. We have to recognize that considerable research efforts are required in order to close or at least reduce this gap. However, there exist wide potentials and a strong need for future research in the area of maintenance, both in theory and practice.

Future research may go in various directions and touch upon various problems and issues of maintenance management. One direction is to examine the empirical laws that govern the current practice of maintenance management, and to devise the best possible ways and means of organizing, planning, controlling and administering the maintenance function. Another direction is the development of theoretical maintenance models that are practical and system-oriented. The Integrated Maintenance Management System and Cybernetic Maintenance Management Process models proposed in this Paper can provide the necessary conceptual framework for future research in the Maintenance area.

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