TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 57, Issue I, March, 2014

SOME ASPECTS ON THE MAINTENANCE MODELS

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Abstract: *The paper examines the need for product maintenance and the distinction among different methods of product maintenance. Several maintenance methods are presented to inform of the variety of approaches adopted to facilitate product design for ease of maintenance. Also, several terms associated with the general topic of product maintenance are presented. The practical utility of each methodology is scrutinized to examine its value in dealing with real-world situations when the product, equipment, and systems are operating in the field.*
Key Words: *design process, maintenance, maintainability, reliability.*

1. INTRODUCTION

A system or product is said to be maintainable or repairable if, when it fails to perform as required, it can be maintained by a suitable methodology, be it repair, overhaul, or replacement either manually or by an automated action [10]. Modern complex systems and products involve a major load on maintenance and support resources, in terms of both personnel and cost.

It is important, therefore, that every effort be to reduce maintenance requirements for newly introduced systems and equipment. Maintenance analysis during the design, acquisition, and selection phase ensures that maintenance requirements are minimized in the future. The ability of a product to work successfully over a prolonged period of time is referred to as *reliability*.

Maintainability can be defined as "the degree of facility with which an equipment or system is capable of being retained in, or restored to, serviceable operation. It is a function of parts accessibility, interval configuration, use and repair environment and the time, tools and training required to effect maintenance" [7].

The U.S. Department of Defense defines *maintainability* as "a characteristic of design and installation which is expressed as the probability that an item will conform to specific conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources" [3]. Given the ongoing discussion regarding the importance of ease of product maintenance, it is clear that designing for maintenance assumes paramount importance in ensuring reliable equipment operation. To that end, reliability actually follows effective maintenance, instead of it being the other way around.

2. CONTENT

Maintenance elements describe the maintenance concepts and requirements for any system. This includes the analysis and verification of customer requirements. The priority selection of each element depends on particular requirements. Figure 1 depicts these elements as well as the interconnections among them.

A study of these elements is necessary to achieve effective maintenance once a system has been conceptualized. To that end, various maintenance elements must be fully integrated and form part of the initial tasks to be performed.

Each of these elements must be controlled and incorporated into system design [10]. It is necessary to realize that the implementation of these elements must be timely and not lag behind the system design.

The International Electro technical Commission has been promoting the idea of customer satisfaction as a measure of reliability and maintainability. Given this background, the maintenance parameter may be depicted in the form presented in Figure 1.

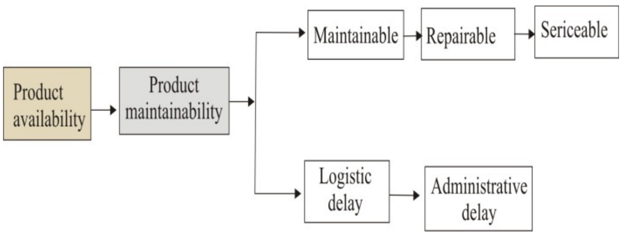

Figure 1. Relationship between maintenance and customer satisfaction (modified from Reiche, 1994).

A sub classification of various maintenance elements is presented in Figure 2. To maintain a product with minimum downtime, it is often necessary to carry out corrective or preventive maintenance, making use of minimal maintenance resources. Examples of such resources include but are not limited to personnel, tools, test equipment, technical expertise, and materials.

2.1. Maintenance Concepts

a.) Corrective (Reactive) Maintenance

Corrective maintenance is reactive in nature. Every time a product or system fails, repair or restoration must follow to restore its operability. The following steps constitute corrective maintenance:

• Once the failure has been detected, it must be confirmed. If the failure is not confirmed, the item generally is returned to service. This no-fault-found problem leads to a considerable waste of time at significant cost.

• If the failure is confirmed, the item is prepared for maintenance and the failure report is completed.

• Localization and isolation of a failed part in the assembly is the natural next step in corrective maintenance.

• The failed part is removed for disposal or repair. Examples of repairable parts and connections include broken connections, an open circuit board on a PCB, or a poor solder.

• The item may be reassembled, realigned, and adjusted after repair. It is checked before being put back to use.

The chief disadvantage of this maintenance procedure is the inherent amount of uncertainty associated with it. Similarly, the procedure is extremely reactive in nature, capable of shutting down an entire operation because of a single failure in a single machine under extreme conditions (often leading to a severe bottleneck and lost productivity).

b.) Preventive (and Predictive) Maintenance

As its name implies, preventive maintenance is carried out to minimize the probability of a failure. Preventive maintenance often is referred to as *use-based maintenance* .

It comprises maintenance activities undertaken after a specific amount of time or equipment use [4]. This type of maintenance relies on the estimated probability of equipment failure in the given interval of time. Preventive maintenance tasks may include equipment lubrication, parts replacement, cleaning, and adjustment (e.g., tightening or slackening). Equipment also may be checked for telltale signs of deterioration during preventive maintenance.

Due to its inherent nature, preventive maintenance must follow maintenance schedules to be fully effective. To that end, preventive maintenance schedules are published for many systems and pieces of equipment.

It is worth noting that corrective maintenance experience exerts the greatest influence on decisions concerning preventive maintenance schedules and procedures [10]. Primary or periodic maintenance inspections may have to be planned to carry out preventive maintenance effectively.

To prepare a preventive maintenance plan, the objectives of the plan should be clear.

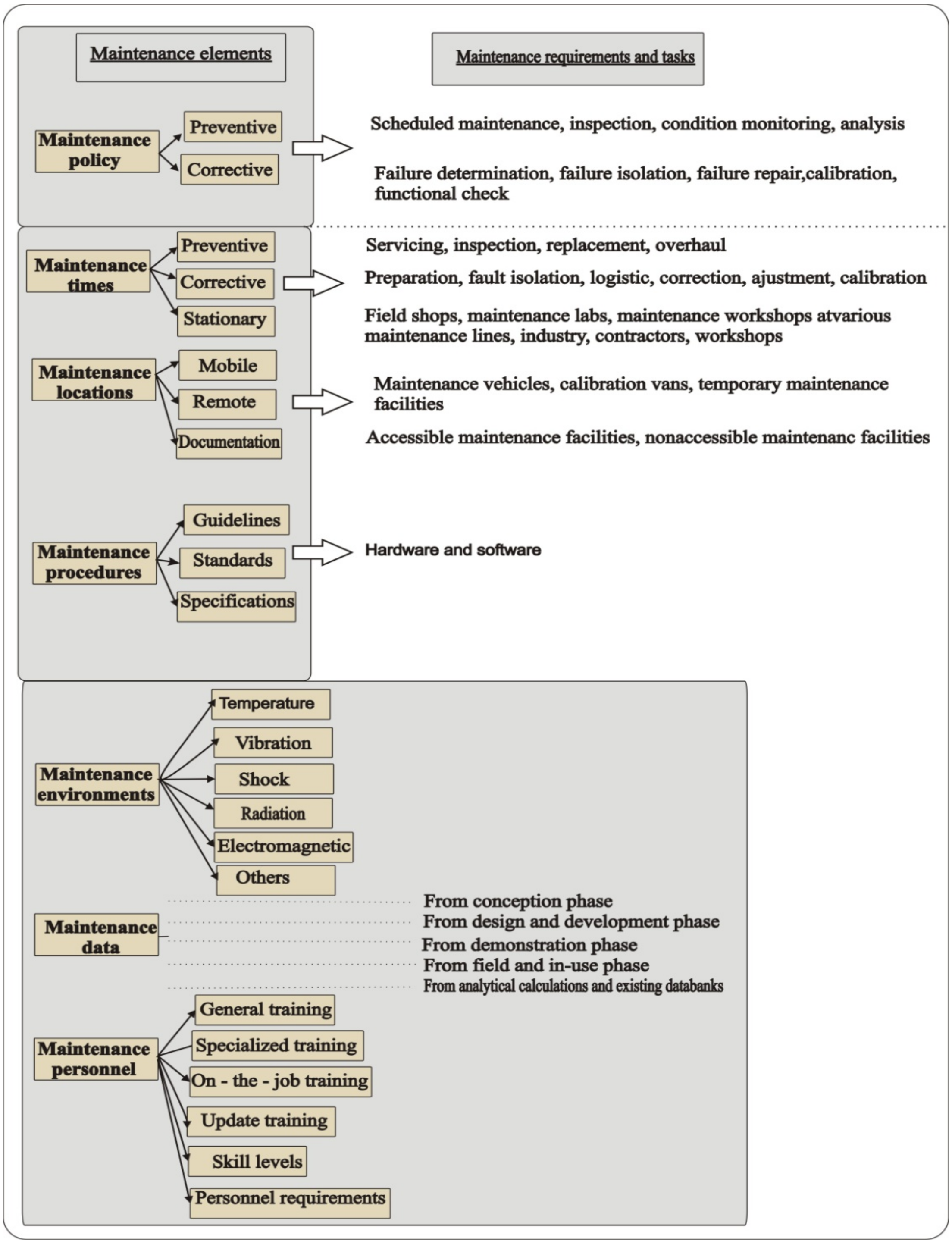

Figure 2. Interrelationship between different maintenance elements (modified from Reiche, 1994).

Examples of such objectives include the following: attempting to maintain system design reliability and availability, reducing corrective maintenance actions, planned maintenance work, and improving the effectiveness of maintenance.

The advantages of preventive maintenance have already been outlined. However, to effect preventive maintenance, equipment has to be taken off-line. The resulting down time is one of the chief disadvantages of this maintenance philosophy.

A chief advantages of predictive maintenance over preventive maintenance is that equipment is taken off-line only when the need to do so is imminent, not after a passage of time, as is the case with preventive maintenance [4]. To summarize, preventive maintenance is performed routinely to accomplish the following three goals [11].:

- Prevent or mitigate failure,
- Detect the onset of failure. Doing this can enable the maintenance engineer to take precautionary actions before a catastrophic failure occurs,
- Discover a hidden failure.

c.) Aggressive Maintenance

It is clear from its nomenclature that aggressive maintenance implies a much more aggressive and far seeking maintenance philosophy than preventive maintenance. An aggressive maintenance strategy seeks to improve overall equipment operation, drawing on the concept of total productive maintenance (TPM). Hence, it is essential to understand the concept of TPM to fully realize the benefits of aggressive maintenance.

Total productive maintenance may be defined as a partnership approach to maintenance. It is a philosophy that chiefly deals with maintenance management designed to complement the implementation of just-in-time systems in Japanese plants. TPM activities seek to eliminate the "six major losses" related to equipment maintenance: equipment failure, setup and adjustment time, idling and minor stoppages, reduced speed, defects in process, and reduced yield.

2.2. Design Review for Maintainability

The emphasis on maintainability does not mean that it should be the only issue on the agenda. As such, it should not be dealt with alone. Other design factors have to be included to arrive at a comprehensive design methodology. It should be clearly understood that maintainability is an integral part of the product design process.

The design review is one of the most important means of achieving good maintainability and reliability. It may be defined as "the quantitative and qualitative examination of a proposed design to ensure that it is safe and has optimal performance with respect to maintainability, reliability and performance variables needed to specify the equipment" [13]. It is useful and necessary to undertake a review at four principal levels of deign:

- Design specification review, including market need in product design,
- System review,
- Equipment (functional unit) evaluation,
- Component analysis.

Nominally, subsystems should be included in the system level review. Similarly, subassemblies should be included in the equipment review.

A comprehensive design review may be characterized by the following distinct stages, as presented in Table 1. A brief description of each activity follows.

2.2.1. Review of Design Specifications.

The objective of the design specifications review is to make certain that all parts and specifications are understood at the outset and the importance of different statements is appreciated. At this stage, the client and design team (either in-house or contracted) should discuss the salient features of the specifications to eliminate any misunderstandings. The specifications is the most common reference point in contractual disputes. Hence, it is in the interest of all to be clear in terms of definitions and requirements. The following specifications are of particular significance in the context of maintainability:

- Maintainability and reliability objectives that are quantitative in nature. This helps avoid any discrepancies in perception.
- A consideration of environmental conditions that may affect maintainability and reliability.
- Particular maintainability requirements need to be addressed in detail, such as the necessity for modular construction, restrictions on the skill level of maintenance workers, and designs that entail multi skill working.

• That the equipment can be effectively and reliably maintained should be demonstrable and acceptance criteria explicitly specified.

Table 1. Structured Design Review Procedure (Modified from Thompson, 1999)

Stage and Activity	Purpose	Timing
1. Review of design specifications	To ensure that the significance of all points contained within the design specifications are understood	Prior to the commencement of any design activity
2. Activity systems level review	▪ To identify critical areas of the design that may affect plant availability and communicate to the detail design teams the necessity to pay particular attention to these areas ▪ To comment on the advisability of pursuing projects with a high risk content ▪ To examine equipment groups to maximize uniformity and stability ▪ To maximize the reliability systems formed by manufacturing and process considerations	Prior to the start of equipment design After the completion of the first equipment designs
3.Equipment (functional unit) evaluation	▪ To evaluate quantitatively critical items of equipment ▪ To undertake qualitative reviews of equipment	After the completion of the first detailed designs
4. Component analysis	To check that certain important sets of components will not give rise to maintainability or reliability problems in service	After the completion of the first detailed design

2.2.2. System Review.

The first system review is done prior to forming detailed designs of the product or equipment. As such, it is necessary to review the parameters of the manufacturing plant in terms of part availability, inventories, buffer capacities, and the like. This is where the issue of what is called *maintenance management* emerges. This stage of the design review identifies critical areas that, if a breakdown occurs, may cause a total plant shutdown.

This stage of the design review should make certain that the appropriate equipment design teams are made fully aware of the presence of any critical areas of the plant [13].

The second stage of the design review enables the designers to complement the initial design by examining equipment groups that have commonalities with seemingly different groups. These are equipment groups that cut across conventional system boundaries. For example, a review of pumps to be used in a plant will reveal whether there is a substantially large diversity of manufacturers (leading to the need for more spares). Keeping this principle in mind, equipment groups should be defined and analyzed to maximize uniformity to reduce spares. Avoiding diverse products enables maintenance teams to more readily build up knowledge and competence in maintenance design practice [13]. Figure 3 depicts the role played by system review in the design process.

2.2.3. Equipment Evaluation

Different items of equipment require different evaluation techniques. The design team has the opportunity to evaluate a design quantitatively at this stage of the design review. Two evaluation methods proposed by researchers are the concept evaluation technique, the device performance index, and the parameter profile analysis.

The concept evaluation technique, proposed by Pugh [9], involves quantitative evaluation in which design concepts are compared to a reference design concept. The reference concept usually is a standard design or a design considered just acceptable. In some cases, it could even be one of the proposed concepts that appeared to be the best on first inspection. However, this method of choosing the standard design is rare.

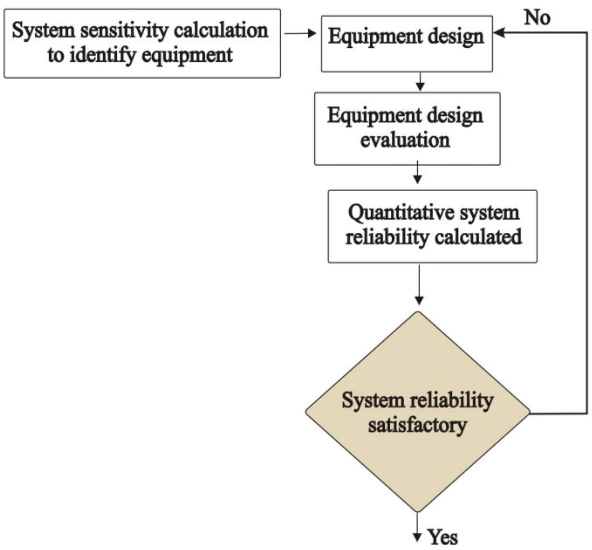

Figure 3. Interaction between system and equipment design levels in a design review (modified from Thompson, 1999).

An evaluation matrix is constructed concepts (1 to *m*) arranged against the evaluation criteria (1 to *n*). To make things easier to understand, a small sketch of each concept could be made on the grid. Each proposed concept is compared to the reference concept, which is chosen as the reference or datum level. If a concept is better than the datum with respect to a particular criterion, a score of (+) is assigned to the concept for that criterion.

Similarly, if the proposed concept is worse than the reference for a particular criterion, a score of (−) is assigned to that concept for the particular criterion. If no judgment can be made, an *s* is assigned, which is equivalent to a score of zero. The scores for each concept are totaled and that with the highest score generally is chosen. The chosen concept then is evaluated to find out if the design can be modified to improve on the negative and null scores. This system of choice caters readily to maintenance criteria early during the design stage.

One of the chief drawbacks of this process is it does not distinguish among the relative importance of various criteria, which would involve assigning a successively higher numerical weights to successively important criteria. Doing this would enable designers to reach a more balanced decision as far as choice of designs is concerned.

Figure 4 depicts the sequential process of generating ideas and concepts for design review.

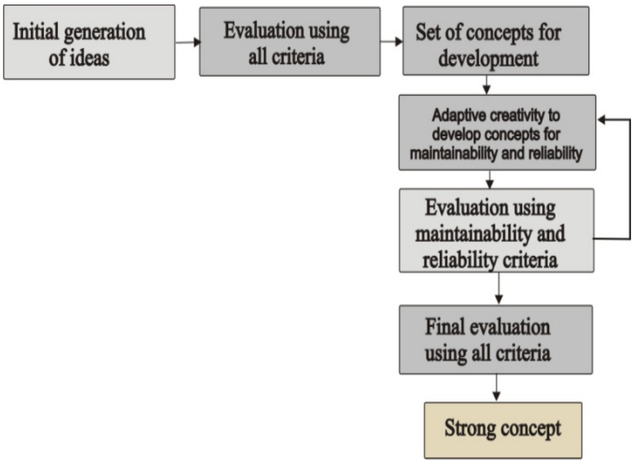

Figure 4. Development of good concepts from initial ideas (modified from Thompson, 1999).

The device performance index (DPI) evaluates equipment that has been designed in detail or compares alternative proposals. It compares quantitative assessments with respect to different performance parameters, including maintainability and reliability. It also can incorporate subjective value judgments.

The DPI is based on an inverse method of combining individual value scores of all criteria for each design concept. The overall value is found by calculating the DPI as follows:

$$\mathrm{DPI} = n \times [(1/u_1) + (1/u_2) + . . . + (1/u_n)]^{-1}$$

where u_i are value scores for each criterion and *n* is the number of criteria.

The parameter profile analysis evaluates equipment performance as well as system characteristics. This analysis method is suited for just such systems. The aim of the evaluation is to identify weak points in the system and highlight areas where system performance is near its limit. The performance parameters that define a system are described in a matrix with respect to the items of equipment.

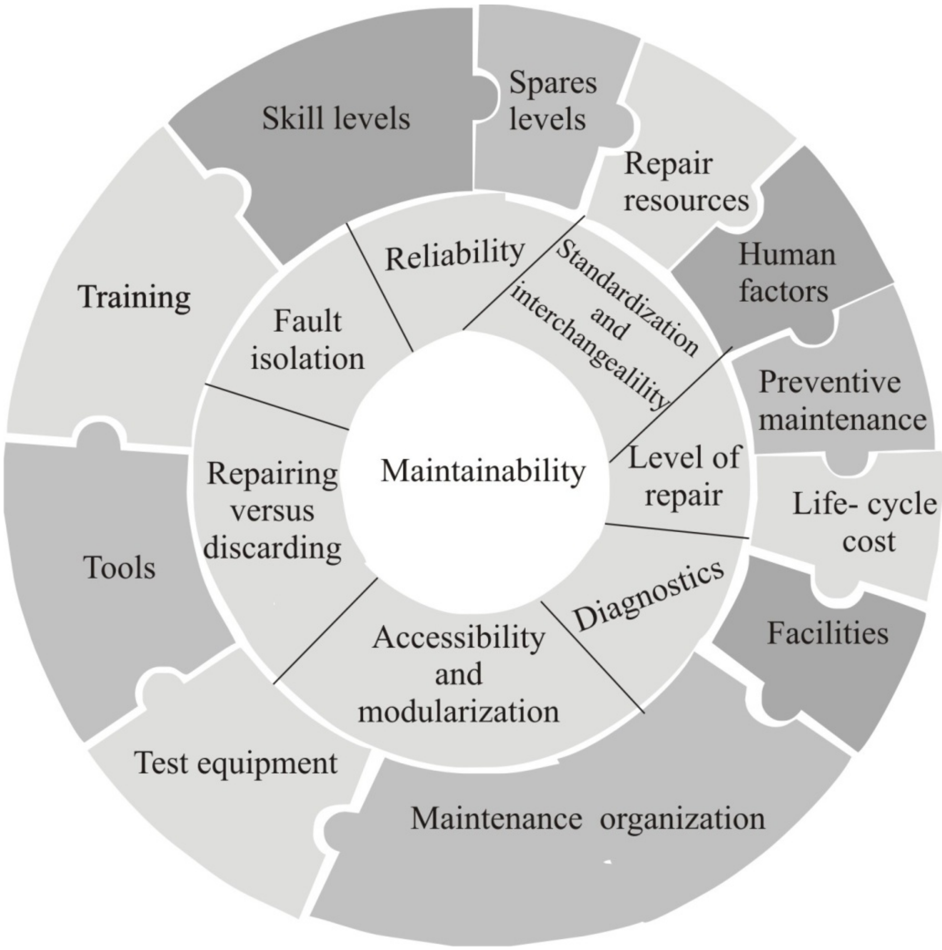

Figure 5. The maintainability universe: Inherent and secondary design features (modified from Ebeling, 1997).

2.2.4. Component Analysis

Component evaluation is clearly different from equipment and system evaluation, because components usually are constituents of a larger system. The question is one of scale; for example, a component may be a bearing, a motor, a gasket, or a rivet. From the perspective of maintainability, it is not practical to consider a general survey of components in a manufacturing plant. In this case, certain component classes need to be identified to facilitate detailed analysis. Examples include components that are functionally important (seals in fluid containers and welded joints, for instance). Experience is important to identify such component classes.

Figure 5 depicts different maintainability design features. A study of the maintainability universe would serve well to impart an introductory idea as to the composition of the maintenance occupation.

3. CONCLUSION

Most systems operate with some sort of degradation occurring throughout their useful lives. To enable the maintenance of such systems, a review has to be done periodically to determine what actions need to be taken. To optimize the maintenance schedule, it has been suggested that the level of degradation be monitored instead of time. This approach enables the addition of factors such as maintenance costs and distribution of degradation.

To maintain a product with minimum down time, it is often necessary to carry out corrective or preventive maintenance, making use of minimal maintenance resources.

Examples of such resources include but are not limited to personnel, tools, test equipment, technical expertise, and materials. The paper outline some basic concepts related to designing for maintenance. It should be noted many of these concepts essentially are maintenance philosophies in themselves, which can be built upon to form a cohesive design for maintenance methodology. Also, a critical examination of various designs for maintenance methods is covered in the paper.

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CÂTEVA ASPECTE ASUPRA MODELELOR DE MENTENANȚA

Rezumat: *Lucrarea examinează mentenabilitatea produselor şi diferenţele între diferitele concepte de mentenanța aplicate. Sunt prezentate pe larg metodele de mentenanța corectiva, preventiva şi agresivă cu intenția de a informa asupra varietății abordărilor adoptate, în scopul facilitării soluțiilor de design pentru optimizarea mentenanței. Sunt trecute în revistă principalele noțiuni şi termeni asociați mentenanței produselor. Utilitatea practică a fiecărei metode este analizată prin prisma valorilor sale în conexiune cu situațiile din lumea reală în care operează produsele, echipamentele şi sistemele. Deasemenea se punctează importanta elaborării corecte şi revizuirii specificațiilor de design pentru asigurarea unei uşoare mentenabilități, în condiții de minimizare a costurilor şi a timpului de imobilizare a utilajelor.*

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