DESIGN FOR MAINTAINABILITY

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ABSTRACT

Design process is an important and crucial stage in any manufacturing process. It is at this juncture where several iterations have to be made to ensure that the final product performs well in accordance with the specifications set. An ounce of design review at the beginning is worth a pound at the end

Much has been said on the importance of preventive and/or corrective maintenance of manufacturing equipment or machines. However less has been emphasized on the importance of maintainability as a design action which provides the equipment or machine an inherent ability to be maintained. All maintenance engineering analysis actions are virtually affected by maintainability inputs to design.

This paper presents the role of the Design for Maintainability as a cost-cutting measure in the maintenance of any equipment or machine. The ease with which a maintenance task can be performed is directly related to the way in which a system has been put together

The authors describe Design for Maintainability as part of the maintenance problem which must be designed into an equipment or system, and therefore, is under the control of the designer. Poor equipment design from a maintenance standpoint contributes heavily and compounds the overall maintenance problem.

In the paper, authors illustrates the importance of Design for Maintainability by given examples from design cases which are frequently performed by design engineers.

INTRODUCTION

Maintainability should not be confused with maintenance. Maintenance are those actions necessary for retaining or restoring an equipment or machine to a serviceable condition. Total maintenance is composed of Preventive and Corrective maintenance [1]

Preventive maintenance is the care and servicing performed for the purpose of maintaining equipment and facilities in satisfactory working condition by providing for systematic inspection, detection, and correction of incipient failures, either before they occur, or before they develop into major defects.

Corrective maintenance is that maintenance performed on a non-scheduled basis to restore the equipment to a satisfactory condition by providing correction of a malfunction which has caused degradation of the item below the specified performance. These two basic maintenance actions can occur while the equipment is in or out of service.

The ease with which the above maintenance tasks can be performed depends on the inherent maintainability (ease-of-maintenance) features designed into an equipment or system [2]. Maintainability reduces downtime, time required to locate and correct faults, by providing ease of access and simplification of adjustments and repair.

In line with maintainability, the designer should also take into account the following:

Improving reliability to reduce the need for maintenance. Reliability must be designed into items to ensure the desired performance for their entire intended life span

Reducing the frequency of preventive (cyclic) maintenance. Reliability improvements often save time and manpower by reducing the frequency of the preventive maintenance cycle. This also means more operational time for the component and/or item concerned.

Reducing the requirements for highly trained specialists. This can be done by simplifying the operation and maintenance of equipment, and utilizing the maintenance support positive concept of modular design for maintenance in operational areas.

Within broad limits, maintainability can partially compensate for hard-to-achieve reliability to obtain the required system availability. Thus, there is also a need to correlate the concepts of reliability maintainability and with each other and with their influence on such factors as system operational readiness, availability and overall system effectiveness.

In short, maintainability is a built-in characteristic of design and installation which imparts to the system or end item an inherent ability to be maintained [3], so as to lower maintenance man-hours, skill levels, tools and equipment, maintenance costs, and achieve greater system availability. It is composed of many factors, such as: inherent simplicity, ease of maintenance, environmental compatibility, safety characteristics, skill level requirements, downtime minimization, life cycle costing, etc.

On the other hand, reliability is a characteristic of a design which results in durability of the system, or end item, to perform its intended function for a specified interval and condition. It is accomplished by selection of the optimum engineering principles, adequate component sizing, material selection, controlling processes and procedures and testing.

System effectiveness is, however, a measure of the degree to which the equipment approaches its inherent capability and achieves ease of maintenance and operation. The relationship, assuming independence of factors, can be expressed as:

$$\text{System effectiveness} = \underset{\text{(How well)}}{\text{Performance}} \times \underset{\text{(How long)}}{\text{Reliability}} \times \underset{\text{(How often)}}{\text{Availability}} \quad (1)$$

If any of the factors on the right side of the equation (1) falls significantly below unity, the effectiveness of the system is seriously impaired. Where one factor falls to zero, system effectiveness becomes zero. Fig. 1 illustrates the relationships among various system properties which together determine the effectiveness of a system. The model illustrates that system effectiveness depends directly on availability, which in turn is a function of reliability and maintainability. Although reliability and maintainability may not be interchangeable in actual design work, they can be considered equivalent when it comes to availability. This is true since an increase in maintainability or reliability or both will increase the availability of the system.

Thus, from a decision-making point of view, availability can be expressed as a function of maintainability and reliability as:

$$A_S = ((R_S, M_S) \qquad (2)$$

where A_S - system availability
R_S - system reliability
M_S - system maintainability

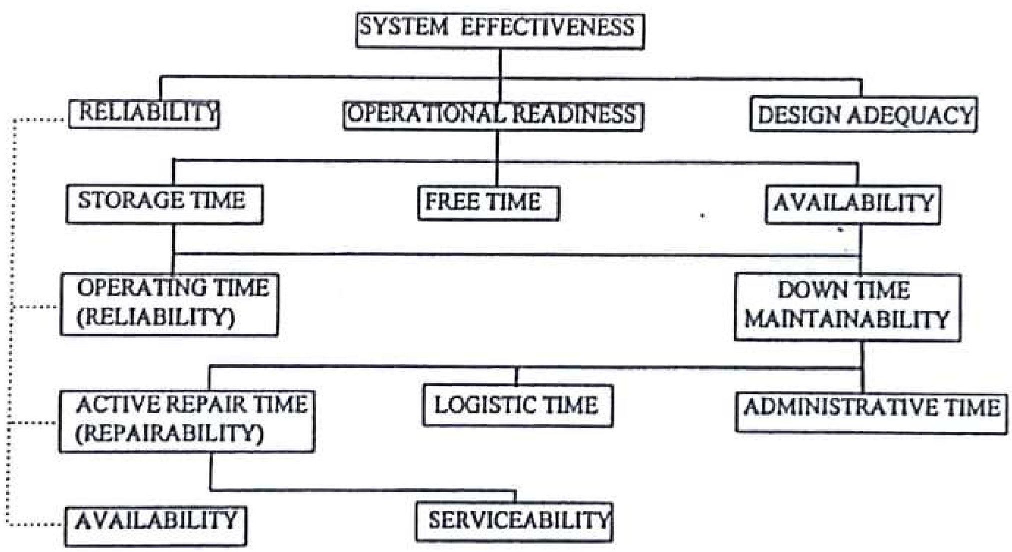

Fig. 1: Maintainability and Reliability as elements of Availability

FACTORS AFFECTING MAINTAINABILITY

Maintenance Personnel Skill and Availability

It is vitally important for the design engineer to consider the skills required and the personnel available to operate and maintain the equipment he/she designed. Equipment that requires skill levels higher than those available can not be successfully maintained. It is also difficult to train and obtain highly maintenance personnel. As the complexity of the equipment increases, the time required to train the operator or maintenance specialist also increases. Complex equipment will generally require greater skill to operate and be more difficult to service. Hence, more vulnerable to human errors when the user is under tension or emotional stress.

Simplicity

It is a general tendency for most designers of equipment to produce an overly complex product [4]. In many cases the equipment uses too many parts; has too close operating tolerances; is too expensive to build, and is difficult to maintain. Equipment design should represent the simplest configuration possible consistent with functional requirements, expected service and performance conditions.

Simplification, although the most difficult maintainability factor to achieve, is the most productive. Simplification should be the constant goal of every design engineer. A complex answer to a set of specification is often easier to develop than a simple answer; six parts can be made to satisfy a group of functions more quickly than a simple equipment with three parts. And it is more costly, initially, to develop a simple equipment than it is to develop a complex equipment. Spending in development, however, may save production and maintenance costs, and more important may increase the effectiveness of the equipment in operations. An ounce of design review at the beginning is worth a pound at the end.

Identification

Identification is an inherent ingredient of maintainability [5]. The maintenance technician's task will be more difficult, take longer, and consequently, increase the risk of error if he cannot readily identify components, parts, controls, and test points for maintenance operations. Proper identification (i.e. proper marking or labelling of parts, components, controls, and test points) is present if the component is readily identified for repair, replacement, or service with minimum effort by the technician.

Accessibility

Inaccessibility is a prime maintainability problem. Ineffective maintenance is often the result of inaccessibility. The technician will tend to delay or omit maintenance actions, make mistakes, and accidentally damage equipment if he cannot adequately see, reach, and manipulate the items on which he must work. Poor accessibility to routine service points and parts of equipment reduces the efficiency and increases the time of the maintenance operation.

Access is made more difficult when there is little space for hands and tools. In such cases there are also risks of injury to personnel as well as to equipment. Inaccessibility also has psychological aspects. The greater the number of accessory steps and the greater the discomfort involved, the more readily the mechanic might perform other tasks less demanding of him; periodic maintenance activities, such as checks and adjustments or troubleshooting, might be unduly postponed or neglected entirely. Inaccessibility is a human factors engineering problem [6]. Fig. 2 shows examples of easily accessible maintenance operations.

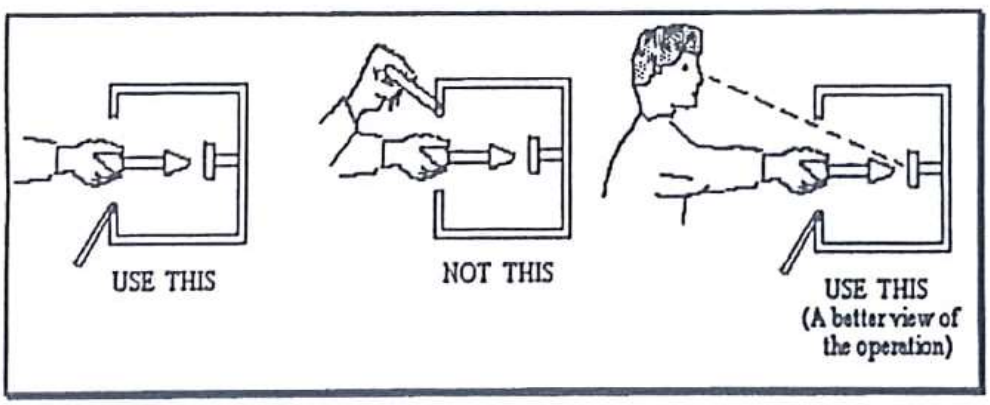

Fig. 2: Easily accessible maintenance operations

An access should be provided wherever a frequent maintenance operation would otherwise require removing a case or cover, opening a connection, or dismantling a component. An access should be designed to make the repair or servicing operation as simple as possible. Fig. 3 gives an example of a problem caused by inaccessibility.

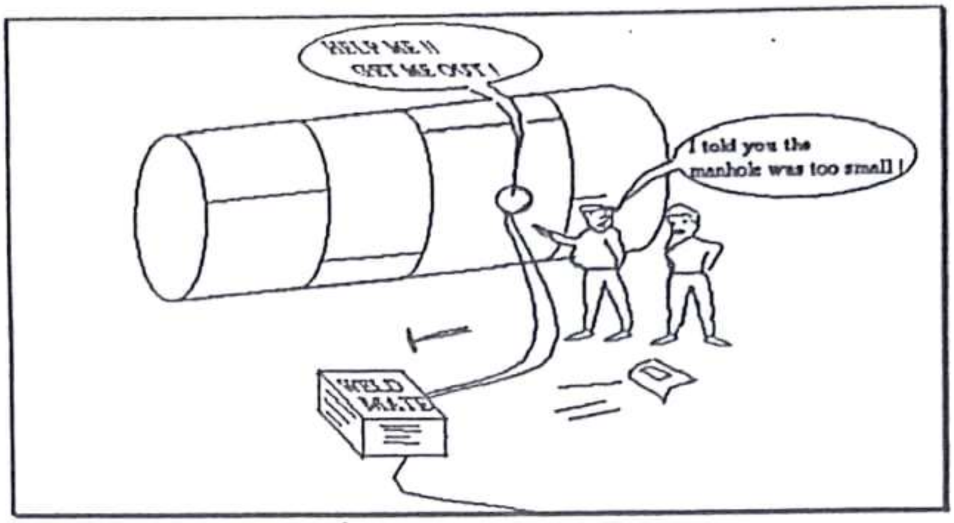

Fig. 3: An example of a problem caused by inaccessibility

Ergonomics

Human factors engineering (Ergonomics) are factors which relates man's size, strength, and other capabilities to the necessary work [7]. Failure to consider these factors will result in increased maintainability problem. To minimize diagnostic time, necessary human factors must be considered and equipment designed to facilitate quick, accurate, and positive action by the technician. Human factors include both human body measurements (anthropometry) and human sensory capacities. Fig. 4 shows some of the body measurements used for equipment design.

Both static and dynamic body measurements are important to the designer. Unlike static body dimensions, which are measured with the subject in rigid standardized positions, dynamic body measurements usually vary with body movements. Dynamic measurements include those made with the subjects in various working positions. In equipment design, dynamic dimensions relate more to human performance than to human fit.

Human sensory capacities include factors such as human sight perception, touch, noise, vibration, motion, etc. Fig. 5 illustrates limits of colour vision.

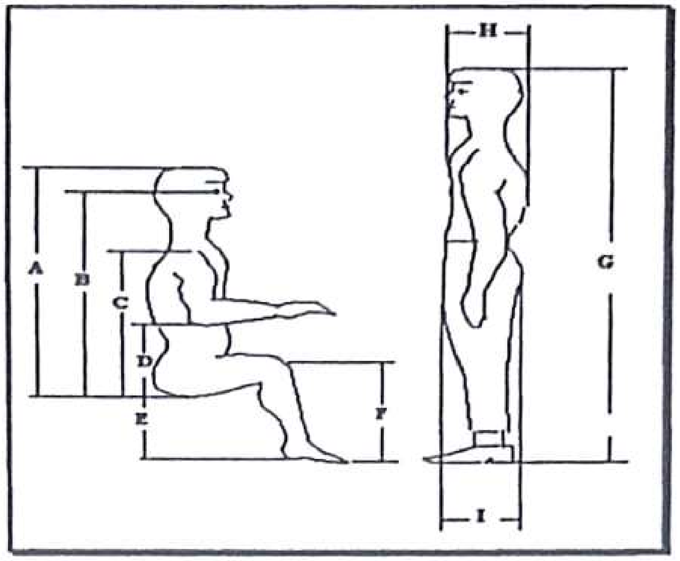

Fig. 4: Some of body dimensions for use in equipment design [7]

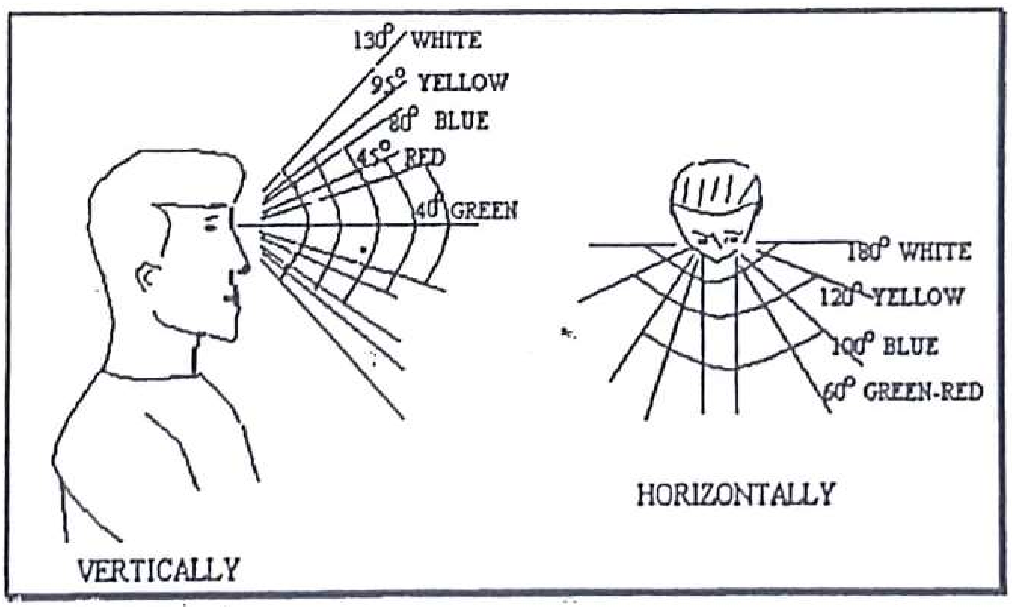

Fig. 5: Approximate limits of normal colour differentiation [6]

Safety

Safety precautions designed into equipment are necessary usually as safeguards to personnel both during operations and service. To minimize the possibility of physical injury, all edges and corners should be rounded to maximum practical radii. Thin edges should be avoided and construction should be such that the unit can be carried without danger of cutting the hands on the edges.

Shields and guards should be made part of the equipment to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, latches, or heavy solenoid equipment. Where such protection is not possible, adequate warning signs should be provided. However, guards should not prevent the inspection of mechanisms, the failure of which will cause a hazardous condition. Guards should also be designed to permit inspection without removal whenever possible. In the cases when this is not possible, guards should be designed to be easily removable and replaceable.

Servicing

Ease of servicing is one of the most important ingredients of maintainability affecting preventive maintenance routines. The purpose of preventive maintenance is to avoid or detect incipient failures in equipment, and ensure that appropriate action is taken before expensive and time consuming repairs or replacements are required.

In many equipment, lubrication is the only maintenance required for long maintenance-free service. Equipment designs are sometimes produced with little thought given to the vast number of maintenance hours required for periodic lubrication and checking of oil levels. Rapid lubrication maintainability should be built into the equipment and equated on an equal design importance with the proper functional design of the equipment.

CONCLUSION

With the help of few examples, it has been shown that Design for Maintainability is an important challenge for designers - a role which can reduce significantly the life cost of a machine. It is therefore apparent that in the training of engineers, and especially for design engineering, maintainability has to be given greater attention than what is currently the case. However, it should be pointed out that in the course of searching for simple and practical designs, a design engineer has sometimes to make a "trade off" of some design factors. The term "trade off", as it applies to maintainability, is the process by which a designer can evaluate one or more proposed maintainability design considerations in terms of possible effects in other areas, and to make an intelligent decision based upon these evaluations. For example, the use of built-in test equipment may minimize downtime required to troubleshoot the equipment, decrease service-induced failures and possible injury to the repairman by allowing fault isolation to be performed without needless probing into the interior of the equipment. However, this will increase complexity of the prime equipment, thus increasing development effort, cost and time. Furthermore, the available space may not permit enough accessibility as shown in Fig. 2.

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