# Consideration of indicators maintainability design

Alami Ayoub*. Naciri oumaima* Herrou Brahim**. El Hammoumi Mohammed**.

**ABSTRACT—** Nowadays, new products on the market are increasingly complex. This complexity stems partly from the fact that the functions that the systems need to require the integration of multiple components using different technologies. The designer must incorporate into its process all phases of the life cycle of the system and its components. Must opt for solutions that are simple to produce, inexpensive, very reliable, safe, easy to maintain and with a total cost over the entire life cycle that is attractive to the consumer. So to validate a feature or product performance, you must have indicators.

In this context we present a systematic analysis of the main indicators of maintainability present in the literature. The aim was to identify those that can be evaluated in design. These indicators are mainly used in operation. The methodology adopted was as follows. At first, the indicators have been identified. In a second step, the parameters for the calculation were identified from their expressions. Third, the sources of obtaining data to calculate these parameters have been identified. Among these sources, they can be exploited in the design were distinguished in fourth place . What has finally deduce indicators can be evaluated design

**Keywords —** Indicators, maintainability, design, performance, life cycle.

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## 1 INTRODUCTION

We will analyze the maintainability indicators used operationally to identify those that can be evaluated in design. To do this, we first recensons indicators used in operation and identify the parameters in their expressions. We then examine the sources of obtaining data to evaluate these parameters. Some of these data sources can be used in design. Their identification allows us to deduce the indicators can be evaluated in the design.

## 2. OPERATING MAINTAINABILITY INDICATORS

Maintainability is the ability of a system to be maintained or restored to a specific operating condition, when maintenance is performed by personnel with the required skills and using prescribed procedures and material resources (Military HandBook - 470A 1997 ). In other words, maintainability is the ease and speed with which a system can be restored to operation after a failure. Several references in the literature present the criteria for a system quiconfèrent a good level of maintainability (Dhillon 1999) (Dhillon 2002) (Ireson et al., 1995) (Ebeling, 1997) (Military HandBook - 791 1988) or (NFX60-301 standard 1982). These criteria are of two types: the criteria inherent in the system itself (intrinsic criteria) and the criteria inherent in the system operating environment (contextual criteria). As intrinsic criteria include: accessibility, disassembly, standardization or interchangeability. As contextual criteria was: human resources (staffing and qualifications), the support material available, the availability of spare parts, environmental conditions or management strategies for production and maintenance.

Maintenance services face a daily challenge: to increase system availability by reducing the duration and frequency of maintenance activities while maintaining a budget. To assess the level of system maintainability and performance meet this challenge, several indicators are available in the literature (Ireson et al., 1995) (Military HandBook - 470A, 1997) or (Blanchard et al., 2005). These indicators are used primarily in operation. They can be grouped into four families (Menye et al., 2007) that we present below. Each indicator can be evaluated for corrective maintenance activities, preventive maintenance activities or simultaneously for both types of maintenance activities. In the following subsections, we present the expressions of these indicators only able to identify the parameters involved in their calculation. No reference to such expressions is made subsequently. It is for this reason that we have chosen to present these terms in summary tables instead of presenting them individually to the line and with numbers.

### 2.1 Indicators duration of maintenance activities

Term indicators of maintenance activities evaluate the duration of the active stages of corrective or preventive maintenance cycle (Table 1) diagnosis (exclusivementpour corrective maintenance), disassembly, replacement / repair, assembly, adjustment, verify the correct operation and running (Military HandBook - 470A, 1997). These steps are called "active" because they are performed on the equipment. For cons, the first step, preparation, is called "inactive" because during its execution, nothing happens on the system which is then awaiting repair. The preparation step includes all previous administrative and logistical operations to the active phase. In the case of a preventive maintenance requiring the system operating stop, the preparation step can be performed by masked time (while the system is still operating) to reduce the downtime of the system.

*Ayoub Alami Doctorant, FST FES, Industrial technology laboratory, university SMBA, B.P. 2202; ayoub.alami@usmba.ac.ma

*Oumaima Naciri Doctorante, FST FES, Industrial technology laboratory, university SMBA,B.P. 2202 ; oumaima.naciri@usmba.ac.ma

**Brahim Herrou Professor, EST FES, Industrial technology laboratory, university SMBA, B.P. 2202 ; herroubrahim@yahoo.fr

**Mohammed El hammoumi Professor, FST FES, Industrial technology laboratory, university SMBA, B.P. 2202; m_elhammoumi@yahoo.fr

Term indicators of maintenance activities are based on the length of the stages of the active phase of maintenance. We will thus measure such as mean, median or maximum active time for preventive maintenance and corrective maintenance or so of preventive and corrective maintenance simultaneously.

TABLE 1
STAGES MAINTENANCE CYCLE

| | Stages | corrective maintenance | preventive Maintenance |
|---|---|---|---|
| Active phase | Preparation | X | X |
| | Diagnosis (rental and insulation failure) * | X | |
| | Component disassembly | X | X |
| | Replacement or repair of component | X | X |
| | Component winding | X | X |
| | Check the health | X | X |

(*) The step of locating the fault is exclusive to corrective maintenance

Recall that the median is the value that separates a population or series into two equal parts. In other words, half of the maintenance operations is less than the median individual duration and the other half has a greater length than the median individual (Dhillon, 2002) and (Blanchardet al., 2005). The maximum maintenance time, meanwhile, is the length (individual) maximum for a given percentage (usually 90% or 95%) maintenance activities (Ireson et al. 1995). When it comes to the median or maximum of the maintenance time active, expression varies depending on the distribution of duration times as indicated in Table 2.

TABLE 2
INDICATORS OF ACTIVE MAINTENANCE PERIODS

| Indicator | | Corrective maintenance | Preventive Maintenance |
|---|---|---|---|
| Active time average | | $MTTR = \frac{\sum_{i=1}^{N} \lambda_i \times MTTR_i}{\sum_{i=1}^{N} \lambda_i}$ | $\overline{M}pt = \frac{\sum_{j=1}^{M} f_j \times Mpt_j}{\sum_{j=1}^{M} f_j}$ |
| | | $\overline{M} = \frac{(\lambda \times MTTR) + (f \times \overline{M}pt)}{\lambda + f}$ | |
| Median time assets | Normal distribution | $\tilde{M}ct = MTTR$ | $\tilde{M}pt = \overline{M}pt$ |
| | Log normal distribution | $\tilde{M}ct = anti\log \frac{\sum_{i=1}^{N} \lambda_i \times \log MTTR_i}{\sum_{i=1}^{N} \lambda_i}$ | $\tilde{M}pt = anti\log \frac{\sum_{j=1}^{M} f_j \times \log Mpt_j}{\sum_{j=1}^{M} f_j}$ |
| | Exponential distribution | $\tilde{M}ct = 0.69 \times MTTR$ | $\tilde{M}pt = 0.69 \times \overline{M}pt$ |
| Maximum time assets | Normal distribution | $Mct_{max} = MTTR + (z \times \sigma_{MTTR})$ <br> z = 1.28 ou 1.65 pour 90% ou 95% | $Mpt_{max} = \overline{M}pt + (z \times \sigma_{\overline{M}pt_i})$ <br> z = 1.28 ou 1.65 pour 90% ou 95% |
| | Log normal distribution | $Mct_{max} = anti\log(\overline{\log MTTR_i} + (z \times \sigma_{\log MTTR}))$ | $Mpt_{max} = anti\log(\overline{\log M pt_j} + (z \times \sigma_{\log Mpt_j}))$ |
| | Exponential distribution | $Mct_{max} = z_e \times MTTR$ <br> $z_e$ = 2.312 ou 3.00 pour 90% ou 95% | $Mpt_{max} = z_e \times \overline{M}pt$ <br> $z_e$ = 2.312 ou 3.00 pour 90% ou 95% |

The average technical repair time and the average time for preventive maintenance of a component i, respectively MTTRi MCTI and are obtained by adding the times of active steps of the corresponding maintenance process.

**2.2 Frequency indicators of maintenance activities.**

Frequency indicators show the average time that elapses between corrective maintenance, preventive maintenance activities two or two corrective and preventive maintenance activities. The corresponding expressions are presented in tableau.3.

TABLE 3
INDICATORS FREQUENCY OF MAINTENANCE ACTIVITIES

| Indicator | Corrective maintenance | Preventive Maintenance |
|---|---|---|
| Mean time between activities | $MTBF = \frac{1}{\lambda}$ | $MTPM = = \frac{1}{f}$ |
| | $MTBM = = \frac{1}{\lambda + f}$ | |

In the particular case of a serial system with rate constant failures, we have: $\lambda = \sum_i \lambda_i$ et $f = \sum_i f_i$ (1)

Another frequency commonly used indicator is the average time between replacements MTBR. This indicator is very important for the design of spare parts. Indeed, it allows determining the component replacement frequency, as some corrective and preventive maintenance activities do not require replacing components.

**2.3 maintenance labor time Indicators**

In this category, the indicators are commonly found: the average time of labor per hour of operation, maintenance activity, permission, per month or per year. The first can be considered as the main indicator (Blanchard et al., 2005). It makes it possible to calculate other indicators of class. Table 4 shows the expressions for the calculation of average labor time per hour of operation and maintenance activity.

TABLE 4
LABOR TIME INDICATORS

| Indicator | Corrective maintenance | Preventive Maintenance |
|---|---|---|
| Average labor per hour of operation | $MLHc/OH = \sum_{i=1}^{N} \lambda_i \times Mct_i \times Nc_i$ | $MLHp/OH = \sum_{j=1}^{M} f_j \times Mpt_j \times Np_j$ |
| | $MLH/OH = \frac{\lambda \times (MLHc/OH) + f \times (MLHp/OH)}{\lambda + f}$ | |
| Hand average time work by activity | $MLHc/MA = \frac{\sum_{i=1}^{N} \lambda_i \times Mct_i \times Nc_i}{\sum_{i=1}^{N} \lambda_i}$ | $MLHp/MA = \frac{\sum_{j=1}^{M} f_j \times Mpt_j \times Np_j}{\sum_{j=1}^{M} f_j}$ |
| | $MLH/MA = \frac{\lambda \times (MLHc/MA) + f \times (MLHp/MA)}{\lambda + f}$ | |

**2.4 Indicators of cost of maintenance activities.**

Maintenance costs take into account factors such as labor (training, salary, etc.), spare parts (purchase, transport, storage, etc.), support equipment (depreciation, operation, etc.), infrastructure (rent, amortization of premises, insurance, etc.), etc. Indicators for assessing these costs are similar to those for labor time to. Thus, it has the average maintenance cost per hour of operation, maintenance activity, per mission, per month or per year. Table 5 presents the formulas for calculating the average maintenance cost per hour of operation and maintenance activity. The other is easily deduced from these two.

TABLE.5

MAINTENANCE COSTS INDICATORS

| Indicator | Corrective maintenance | Preventive Maintenance |
|---|---|---|
| Cost per hour operation | $MCc/OH=\sum_{i=1}^{N}\lambda_i \times MCc_i$ | $MCp/OH=\sum_{j=1}^{M}f_j \times MCp_j$ |
| | $MC/OH=\frac{\lambda\times(MCc/OH)+f\times(MCp/OH)}{\lambda+f}$ | |
| Average cost per activity | $MCc/MA=\frac{\sum_{i=1}^{N}\lambda_i\times MCc_i}{\sum_{i=1}^{N}\lambda_i}$ | $MCp/MA=\frac{\sum_{j=1}^{M}f_j\times MCp_j}{\sum_{j=1}^{M}f_j}$ |
| | $MC/MA=\frac{\lambda\times(MCc/MA)+f\times(MCp/MA)}{\lambda+f}$ | |

In summary, we have presented above maintainability indicators used in operation. We have grouped into four families: duration of maintenance activities indicators, frequency indicators of maintenance, labor time indicators and indicators of costs of maintenance activities. Tables 5 present the expressions of the indicators of each family. These expressions allow us to identify the parameters to be evaluated to estimate each indicator. We present in the following two subsections sources of obtaining data for evaluating these parameters during operation and the system design phase.

## 3 OBTAINING DATA

The previous subsection has allowed us to identify the parameters needed to calculate the maintainability indicators used in operation. These parameters are:
-The rates of components failures, $\lambda_i$.
-The frequencies of preventive maintenance activities, $f_j$.
-The average repair time of technical components, MTTRi
-The average time of execution of preventive maintenance activities, Mptj.
-The number of corrective maintenance to affected operators of each component, Nci.
-The number of operators assigned to each preventive maintenance activity, Npj
-Corrective maintenance costs of components, MCci
-The costs of preventive maintenance activities, MCpj.

### 3. 1 operation Data Sources

- Main source of obtaining operating data: the system life history.

In the operational phase of a system, the rates of $\lambda_i$ breakdowns and repair techniques MTTRi time Mptj and preventive maintenance are estimated mainly from the life history of the system. This historic, if well informed, contains information on all events in the life of the system since its installation. If the records are successful, the system's history of life will have the information such as the system stops dates, causes of stops, repairs, operators who carried out the repairs, and delivery dates condition. The analysis of this information to determine parameters such as $\lambda_i$, MTTRi, Mptj, and to some extent, Nci and Npj.

- Sources for obtaining frequencies of preventive maintenance activities fj frequencies of preventive maintenance activities are often provided by the system manufacturer. Indeed, it defines general preventive maintenance activities (replacement of a component, lubricant, etc.) to run on the system, and their execution frequency data in operating conditions. However, the actual operating conditions of the system may differ from those defined by the manufacturer. This may require an adjustment of the frequency of preventive maintenance activities. In this case, the new fj values can also be inferred from the analysis of the history of the life of the system.

- Sources for obtaining cost of maintenance activities Costs MCci and MCpj, meanwhile, are evaluated through tools such as cost accounting or the ABC method (Activity Based Costing). But this assessment is difficult because of the complexity of the factors to be considered: the cost of spare parts (purchase, transport and storage), labor costs (hiring, training and wages), cost tooling (acquisition, depreciation, operation).

Therefore, apart from cost, other parameters can be obtained, in operation, from the history log of life, when it exists. However, this is not always the case. In the absence of history, for example at the beginning of the operational phase of a new system, certain parameters, including $\lambda_i$, $f_j$, MTTRi Mptj and can be obtained from other sources listed below. The new system design phase is also a phase in which no history is available; these sources can also be exploited in the design. We present in the next section.

### 3. 2 Other data sources that can be exploited in the design

- For obtaining component failure rates, $\lambda_i$.

In the design phase, the designer integrates the components in a solution can be separated into two groups. The first consists of components which are identical or similar models have been used in other existing or existed systems (eg standard components). The second group consists of the new components, designed specifically for the generated solution. Although the system history of life is completely non-existent in the design stage, we can find data on the components of the first group. This data comes from the historical existing systems (or existed) in which these components have already been integrated. Several reliability data collections are available in various sectors. The reliability of data collection activity peaked in the 1980s she was unfortunately less intense in the 1990s and since that time, the majority of published databases has not been updated (Smith , 2005). The available databases can be classified into three categories:

Specific databases to a company or to an industrial site: these are data collected similar equipment used in similar conditions by a company.

Specific databases to an industry: Data are from a particular industry (telecommunications, nuclear, military, etc.)

Generic databases: data from several sectors and from many sources. These databases often have mathematical expressions that are regression models to estimate failure rates, for example.

For the components of the second group (components specifically designed for the system under development), $\lambda_i$ can be evaluated either by similarity when there are more or less similar components in the first group for which databases are available or by Bayesian approaches for estimating parameters taking into account both expert knowledge and experimental data, then either by virtual tests whose feasibility has been demonstrated (Zwingmann, 2005) or by testing accelerated.

- Obtaining and MTTRi Mptj.

The MTTRi and Mptj represent the sum of the durations of the stages of the active phase of corrective and preventive maintenance, respectively (Table 3). Some databases as OREDA provide repair times of the components. It is also possible to estimate the duration of each step of the active phase maintenance of a system in the design phase, from the CAD model. For example, the evaluation of the duration of disassembly or reassembly of the component is possible because on the one hand, the disassembly of algorithms (Lambert, 2003) or (Zwingmann et al., 2008) and, hand, the existence of standard time databases basic maintenance actions (screwing, crimping, etc). With these two elements (disassembly algorithms and time standard basic maintenance actions), disassembly of the time can be estimated from a component as follows: we apply the algorithm to the disassembly of the system CAD model to determine the sequence optimum component disassembly. Knowing the product structure, this sequence will help to determine the different undoing connections to access the component. By assigning to each link the appropriate standard time, one can estimate the time of removal and disassembly of the component. A mathematical model based on this principle and to optimize disassembly time is proposed in (Menye et al, 2009). The durations of the other steps of the active phase maintenance can be estimated using some of the above methods (Bayesian approach, similarity, etc).

## 4 Maintainability Indicators That Can Be Evaluated Design

Ultimately, the expressions of the four families of maintainability indicators available in the literature involve the following parameters: failure rates (λi), the frequencies of preventive maintenance activities (fj), average repair techniques time components (MTTRi), average execution time of preventive maintenance activities (Mptj), the number of operators assigned to the corrective maintenance of each component (Nci), the number of operators assigned to each preventive maintenance activity (NPj), the costs of corrective maintenance activity (MCCi) and the costs for preventive maintenance activity (MCpj). We have modified the above analysis of the sources of obtaining these parameters assessment data. This analysis shows that it is possible to estimate some of them in particular λi, fj, $MTTR_i$ and Mptj, in the design phase, through various data sources such as the many reliability databases collected by various agencies (table 5). The four parameters, λi, fj, $MTTR_i$ and Mptj, are the only ones involved, how to show the table 6 in expressions indicators duration and frequency of maintenance activities indicators. These two families are those which can be evaluated with less difficulty in the design phase.

TABLE 6
Summary of parameters in each family maintainability indicators

| | $\lambda_i$ | $f_j$ | $MTTR_i$ | $Mpt_j$ | $Np_i$ | $Nc_i$ | $MCc_i$ | $MCp_i$ |
|---|---|---|---|---|---|---|---|---|
| Duration | x | x | x | x | | | | |
| frequency | x | x | | | | | | |
| Workforce | x | x | x | x | x | x | | |
| cost | x | x | | | | | x | x |

In sum, four sets of indicators are used in the literature. In each family, the indicators are calculated from the same parameters. We have shown that two families of indicators can be evaluated by design: term indicators and frequency of maintenance activities indicators. The choice of one or more indicators depends on the end-user and the data available for evaluation. An aggregate indicator that combines several indicators can also be used as needed.

## 5 Conclusion

We analyzed the maintainability indicators used in operation to identify those that can be evaluated in the design. This analysis allowed us to conclude that term indicators of maintenance activities and frequency of maintenance activities indicators could be used in design to evaluate the maintainability of a system.

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