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Towards the Design of a new Framework for Maintenance Costing

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Abstract

The development of any maintenance management system should provide a strategic vision covering the whole life cycle and allow for maintenance improvement as an important part of the total performance of any system. In this paper, a new typology and model for maintenance costing is suggested. This model considers maintenance costing as a continuous improvement tool instead of being only a mean of reporting. The suggested model may be useful for measuring the part of each maintenance activity or action in the creation of the maintenance total cost and therefore identifying the activities, elements and actions to be improved in priority in order to reduce the system life cycle cost.

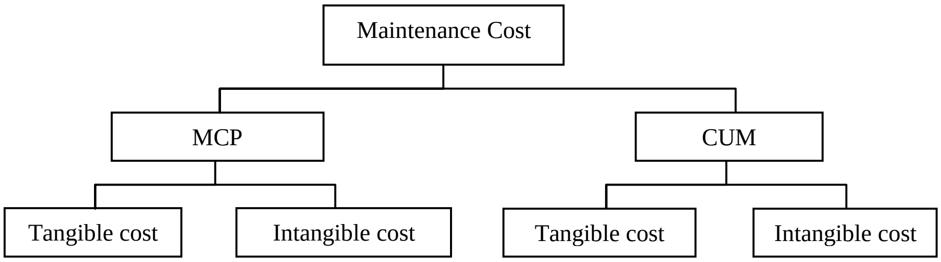
Keywords: Cost of planned maintenance, cost of unplanned maintenance, tangible cost of maintenance, intangible cost of maintenance, life cycle cost, continuous improvement

1 Introduction

Maintenance function plays a strategic role, particularly in the large companies where maintenance costs represent a significant part of their operational budgets [1]. In order to achieve successfully his mission, the manager of maintenance function needs a tool that allows him to evaluate the current situation of the maintenance function and to estimate its evolution, in order to make the appropriate decisions at the convenient moments. This tool should reflect all the elements composing the maintenance function, as well as the relations between the maintenance and other functions, particularly, the production function. The use of language of costs is able to meet these needs. However, the application of this language on the maintenance process (maintenance costing) should not be only of operational interest but also strategic, it should not only allow an optimization of the resources used by the maintenance process but also an optimization at the holistic level of the system, it should not only describe the current situation but also to encourage the continuous improvement and obviously it must be well defined, simple and flexible. The adoption of the concept of "life cycle cost" (LCC) by the maintenance costing, meets properly these conditions.

Nevertheless, there is an important lack of scientific works on costing issues of maintenance. Among the limited number of works that have been devoted to the matter, it is of interest to cite the following works. A framework for costing the planned maintenance jobs was developed in [4] by using a case study. In [5] was discussed the idea of combining the activity-based costing methodology with the discrete event simulation in order to allocate more efficiently the shared indirect maintenance cost to the individual machines. The time-driven activity-based approach was suggested in [3] for modeling the maintenance cost. The results of using the activity-based costing (ABC) as an approach for allocating the overhead cost of maintenance were compared in [2] with those obtained from the traditional cost accounting system. The author in [2] recommended using the ABC when charging maintenance job orders.

In this paper, a new typology and framework for maintenance costing is proposed. The suggested framework considers maintenance costing as a continuous improvement tool instead of being only a mean of reporting. This framework meets the different requirements cited above. For doing so, two categories of costs that can be generated by the maintenance process during the system life cycle were defined. These costs are the Cost of Planned Maintenance (CPM) and the Cost of Unplanned Maintenance (CUM). CPM is the sum of all costs generated by the different maintenance actions, required by the various maintenance plans of the system, during its life cycle. CUM is the sum of all costs generated by the various maintenance actions that were not taken into account by the various maintenance plans of the system. Each type of maintenance cost can generate two kinds of costs, a tangible cost and an intangible cost. The tangible cost relates to the resources consumed or used to carry out this action. The intangible cost represents the impact of the maintenance action on production, quality and environment. Figure 1 summarizes the different type of maintenance costs mentioned above.



This paper suggests in the following two sections a model for estimating the two different types of costs that compose the total cost of maintenance. The last section in this paper outlines the utility of such a model in the improvement of the maintenance management.

2 Cost of Planned Maintenance (CPM)

Maintenance resources can be distributed in several manners, for example, according to the:

- maintenance types: preventive maintenance (predetermined, condition based) or corrective maintenance (deferred, immediate)
- intervention place: on site or out site
- maintenance activities: inspection, routine maintenance, overhaul, rebuilding, repair, improvement, etc.

The distribution adopted in this framework attaches the resources to the activities of sub-processes which use them. Thus, the resources of maintenance will be distributed according to the maintenance sub-processes: piloting, planning, programming and realization of the maintenance interventions. Figure 2 shows the relations between these four maintenance sub-processes.

In order to estimate the tangible cost of maintenance (*CT*), a system composed of *K* elements, is considered, where:

- $k \in \{1, \ldots, K\}$ denotes the element of a system;
- $j_k \in \{0, 1, \ldots, J_k\}$ denotes the maintenance action *j* carried out on element *k*, in accordance to the maintenance plan traced for the system;
- $i_k \in \{0, 1, 2, \ldots\}$ denotes the maintenance action *i* carried out on element *k*, not taken into account by the maintenance plan traced for the system;
- $n(j_k)$ estimates the occurrence numbers of the actions j_k during all the system life cycle and $n(i_k)$ estimates the occurrence numbers of the actions i_k during all the system life cycle.

Let $CT(j_k)$ denotes the tangible cost necessary to carry out the maintenance action *j* on the element *k* of the system and $CIT(j_k)$ denotes the intangible cost (impact) of carrying out the maintenance action *j* on the element *k*. Thus:

$$CPM = \sum_{k=1}^{K} \sum_{j_k=0}^{J_k} [n(j_k) \times (CT(j_k) + CIT(j_k))]$$

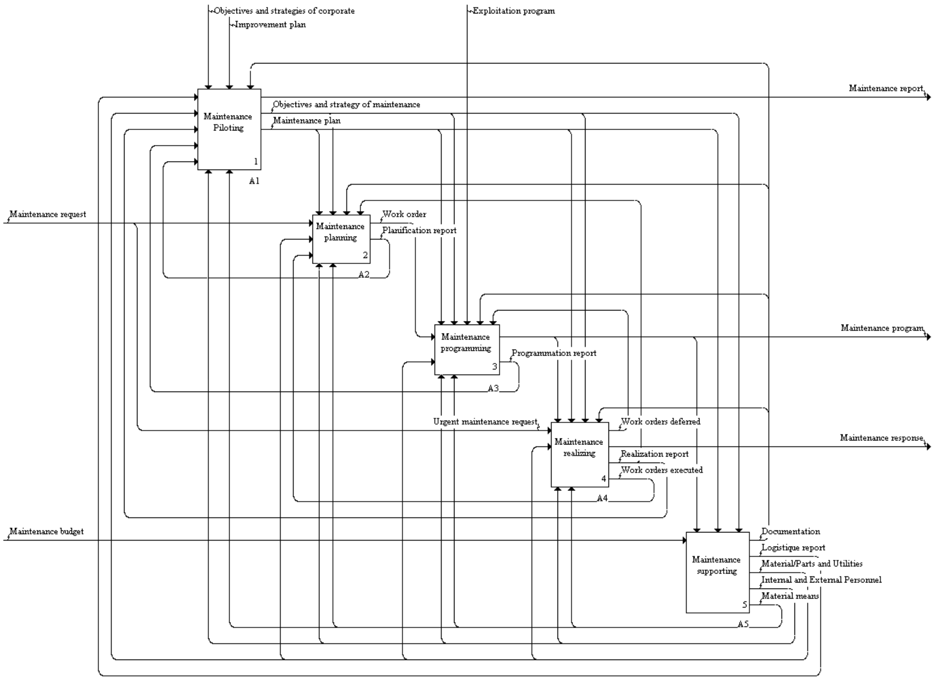


Figure 2: maintenance sub-processes

In order to estimate $CT(j_k)$, the following method based on the Time-driven ABC is suggested:

Step 1: estimate the cost of the maintenance sub-processes: piloting, planning, programming and realization denoted respectively C_{PILO}, C_{PLAN}, C_{PROG} and C_{REAL}. To estimate the costs of the maintenance sub-processes (piloting, planning, programming and realization of the interventions), the following approach is suggested:

- estimate the consumption or the use of each sub-process of each maintenance resources categories (personnel, materials/parts, utilities, information, material means and external suppliers),
- add different consumptions estimated in order to obtain the costs C_{PILO}, C_{PLAN}, C_{PROG} and C_{REAL}.

Let C_{ij} (see table1) denotes the consumption (or the use) of the resource j by the sub-process i, then:

$$C_i = \sum_{j=1}^{6} C_{ij} \qquad , \qquad i \in \{1,2,3,4\}$$

All the costs C_{ij} are easily identifiable, only the resource which is used by two or more sub-processes requires an attribution key. For example, it is possible to find the sub-processes piloting, planning and programming gathered in the same building. In this case it is appropriate to distribute the building depreciation charges proportionally to the surfaces occupied by each sub-process.

Table 1: distribution of maintenance resources

Resources/Sub-process	1. Piloting	2. Planning	3. Programming	4. Realization
1. Personnel	C_{11}	C_{21}	C_{31}	C_{41}
2. Materials	C_{12}	C_{22}	C_{32}	C_{42}
3. Utilities	C_{13}	C_{23}	C_{33}	C_{43}
4. Information	C_{14}	C_{24}	C_{34}	C_{44}
5. Material means	C_{15}	C_{25}	C_{35}	C_{45}
6. External suppliers	C_{16}	C_{26}	C_{36}	C_{46}
Total	C_{PILO}	C_{PLAN}	C_{PROG}	C_{REAL}

Step 2: distribute the costs C_{PILO}, C_{PLAN}, C_{PROG} and C_{REAL} on the actions j_k
Step 3: attach C_{PILO}, C_{PLAN}, C_{PROG} and C_{REAL} to the element k of the system.
The intangible cost $CIT(j_k)$ includes the impact of the maintenance process on production, quality and environment.

Maintenance impact on production will be measured by the sum of:

- $C_{OPP}(j_k)$: production forgone
- $C_{EXP}(j_k)$: production cost engaged (personnel costs, services and fixed assets) without any counterpart
- $C_{RET}(j_k)$: penalty for delayed delivery of products.

The opportunity cost $C_{OPP}(j_k)$ caused by the down state of the system related to the action j_k is estimated by:

$$C_{OPP}(j_k) = C_{OPPU} \times T_{INDIS}(j_k) \times \alpha(k)$$

Where C_{OPPU} indicates opportunity cost per time unit, estimated by the sales turnover per time unit ; $T_{INDIS}(j_k)$ represents required time whereas the system is in down time due to the action j_k and $\alpha(k) \in [0,1]$ denotes percentage of the production forgone caused by the down state of the element k.
The cost of exploitation $C_{EXP}(j_k)$ engaged without any counterpart due to the action j_k is given by the expression:

$$C_{EXP}(j_k) = T_{INDIS}(j_k) \times (C_{EXP} / H_{EXPL}) \times \alpha(k)$$

Where C_{EXP} indicates production cost of the system (the material cost is not included) and H_{EXPL} denotes practical capacity of production.
The penalty for delayed delivery of products $C_{RET}(j_k)$ caused by the action j_k is estimated by:

$$C_{RET}(j_k) = T_{INDIS}(j_k) \times C_{RETU}(k)$$

Where $C_{RETU}(k)$ denotes the penalty delay per time unit related to down state of the element k.
The impact of maintenance on quality is measured by the sum of:

- $C_{OPPQ}(j_k)$: production forgone due to quality tests
- $C_{EXPQ}(j_k)$: production cost (including the material cost) used to produce rejects and wastes
- $C_{RETQ}(j_k)$: penalty for delayed delivery of products, if the time of tests (checking-out, starting up, etc.) causes penalty delay.

The $C_{OPPQ}(j_k)$ caused by carrying out tests (checkouts, starting-up, etc.) after the maintenance action j_k is estimated by:

$$C_{OPPQ}(j_k) = C_{OPPU} \times T_{ESSAI}(j_k) \times \alpha(k)$$

Where C_{OPPU} indicates opportunity cost per time unit and $T_{ESSAI}(j_k)$ denotes testing time after the realization of the action j_k.
The production costs $C_{EXPQ}(j_k)$ caused by carrying out the tests after the realization of the action j_k is estimated by:

$$C_{EXPQ}(j_k) = T_{ESSAI}(j_k) \times (C_{EXPQ} / H_{EXPL}) \times \alpha(k)$$

Where C_{EXPQ} denotes production cost (including the material cost consumed by the production process)
The delay penalty associated with the time of carrying out the different tests after the realization of the action j_k is estimated by:

$$C_{RETQ}(j_k) = T_{ESSAI}(j_k) \times C_{RETU}(k)$$

In order to evaluate the effect of maintenance on the environment $C_{ENV}(j_k)$, the following method is suggested:

a) Identify the rejects or wastes $rj_k \in \{0,1, \ldots , Rj_k\}$ that can be generated by the maintenance action j_k.

b) Estimate the treatment cost necessary for the elimination of the waste rj_k in form of a percentage $\lambda(rj_k)$ of the production cost (C_{EXPQ})

The intangible cost related to the environment which can be generated by the maintenance carried out on the element k can be expressed as follows:

$$C_{ENV}(j_k) = \sum_{rj_k=1}^{Rj_k} (\lambda(rj_k) \times \mathrm{C}_{\mathrm{EXPQ}})$$

3. Cost of Unplanned Maintenance (CUM)

In the estimate of the cost CPM, it was supposed that the actions of maintenance are preliminary known. That is not verified in the case of the unplanned cost. For this purpose, the following steps were suggested in order to

identify the required maintenance actions $i_k \in \{0,1,2,\ldots\}$ to carry out on the element k and that were not included in the maintenance plans.
Step 1: determine the duration of the system life cycle
Step 2: identify the strategic system elements $k \in \{1,\ldots,K\}$ that necessitate maintenance
Step 3: identify, for each element k, the potential failures modes d_k
Step 4: identify, for each failure mode, the extreme exclusive possible scenarios of failure s_{d_k} ($\forall\ s'_{d_k} \neq s_{d_k}$: Probability [$s_{d_k} \cap s'_{d_k}$] = 0) which are not considered by the maintenance plans. Considering exclusive scenarios avoids the double account of costs.
Step 5: for each possible failure scenario s_{d_k} :

1. estimate the number of occurrence $n(s_{d_k})$ for the whole duration of the system life cycle (example: 2 times during 50 years)
2. identify the final effect
3. select the appropriate actions $i(s_{d_k})$ if the failure scenario s_{d_k} occurs
4. calculate for each action $i(s_{d_k})$ its tangible cost $CT[(i(s_{d_k})]$ and its intangible cost $CIT[i(s_{d_k})]$ as was done with the cost of planned maintenance
5. calculate the maintenance cost corresponding to the occurrence of the failure scenario s_{d_k} during all the system life cycle, which is given by the expression:

$$Cost(s_{d_k}) = \sum_i (n_i \times [CT(i(s_{d_k})) + CIT(i(s_{d_k}))]$$

Step 6: calculate the cost of unplanned maintenance due:

1. to the failure d_k : $\sum_s Cost(s_{d_k})$, then
2. to the failure of the element k : $\sum_d \sum_s Cost(s_{d_k})$

Then,

$$CUM = \sum_{k=1}^{K} \sum_d \sum_s Cost(s_{d_k})$$

4 Role of the framework in the maintenance improvement

The life cycle cost has a generic nature and offers a suitable framework to choose the best manner of using the rare resources by a system. In general, it is possible to distinguish four principal processes in the functioning of a system: piloting, exploiting, maintaining and supporting. Therefore the following costs were considered: Investment cost (C_{INV}), exploitation cost (C_{EXP}), maintenance cost (C_{MAIN}) and disposal cost (C_{ELI}). It is important to note that the cost related to the environment will be attached to the investment cost in the case of prevention against the negative incidences on the environment or to the exploitation cost is the case of penalties or costs for the waste treatment.

The life cycle cost estimated at the instant t (LCC_t) can be written as:

$$LCC_t = C_{INV_t} + C_{EXP_t} + C_{MAIN_t} + C_{ELI_t}$$

After replacing the maintenance cost by its two components, LCC_t becomes:

$$LCC_t = C_{INV_t} + C_{EXP_t} + CPM_{MAIN_t} + CUM_{MAIN_t} + C_{ELI_t}$$

The improvement of the maintenance function, according to the LCC approach, must be made within the framework of the system performance improvement. This signifies that any improvement of one of the constituent elements of the maintenance function is significant only if it results in a reduction of the *LCC*. So, the objective is the reduction of *LCC* instead of the reduction of C_{MAIN}.

Conclusion

In this paper, a new framework for costing maintenance was suggested. In this framework, the cost of maintenance was divided into cost of planned maintenance and cost of unplanned maintenance. The first one refers to the preventive or corrective actions of maintenance given in the plans traced to maintain the system during all its life cycle. The second one is related to the maintenance actions carried out following failures not taken into account by the plans of maintenance. In each type of costs, two types of costs were identified: tangible cost and intangible cost.

Maintenance costing was often used as a mean for reporting. This paper illustrated that it is possible to use maintenance costing to measure the part of each maintenance activity, each system element or each maintenance action in the creation of the maintenance total cost. The estimate of the maintenance total cost as presented in this paper, allows the identification of the critical elements having a significant effect on the life cycle cost and to propose on their basis a plan for the continuous improvement of the system.

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