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The measurement of maintenance function efficiency through financial KPIs

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Abstract. The measurement of the performance in the maintenance function has produced large sets of indicators that due to their nature and disparity in criteria and objectives have been grouped in different subsets lately, emphasizing the set of financial indicators. The generation of these indicators demands data collection of high reliability that is only made possible through a model of costs adapted to the special casuistry of the maintenance function, characterized by the occultism of these costs.

1. Introduction

The indicators of maintenance performance are sustained in three pillars i.e.: RAMS parameters, a cost model and the human factor, [1]. An agreed cost model in maintenance is formed as the base necessary to compose the corpus of the financial indicators, in addition form an excellent group in the general set of indicators of the performance of a company.

The financial measures usually consider the upper layer in the hierarchy of the organization and are used habitually by the top management. These indices, demonstrate the capacity of the organization to obtain a good return of their assets and to create value. The metric at this level is commonly used for the strategic planning. For that reason it constitutes the traditional pillar of the organization. This level of measurement can also be used to compare the performance of the different departments and divisions within the same organization. Authors including Vergara [2] propose the use of net present value as a financial indicator, Hansson [3] advocate the use of other financial indicators in maintenance field including: the percentage variation of the sales, performance of the sales, the percentage change in the total of assets and the percentage change in the number of employees.

The incorporation of financial indicators to the maintenance scorecard according to Hendricks & Singhal [4] is the search for the unicity of criteria and tendencies between maintenance and the corporative strategy. Equally, Coelo & Brito [5] set out the necessity of an integration and correlation, in a harmonic way, of the indicators of financial performance of the organization, which deals with the strategic vision with the ones referring to the efficiency of the maintenance function. Cáceres [6]

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analyzes within the four perspective of the Balanced Scorecard (BSC) in maintenance the financial perspective. All planning systems must show the history of the strategy and the positioning of the corporation indicated by the financial objectives, tying them soon to the sequence of actions that must be realized with the clients, process and commit finally with the own employees. This perspective is centered in the capital performance, the added value to the organization and the reduction of unit costs in the case of companies of services. In the case of maintenance, it is there where the cost of each activity and the incidence meter of maintenance costs in each production unit and costs of maintenance regarding the value of the assets are monitored: all this are world-wide accepted and considered for benchmarking.

The incorporation of all these indicators demands an agreed model of costs, main preoccupation to realize suitable benchmarking of these indices. The necessity of comparison and search of benchmark points in the calculation of the Key Performance Indicator (KPI) demands a parity in the calculation, being the quotient of two costs and therefore attributable directly to the implanted financial model.

This impossibility and lack of consensus in the models of costs and therefore the disparity of the calculated indices has an immediate consequence in the existence of only two indices of world-wide class, i.e. general consensus, regarding the finances in maintenance:

- Cost of Maintenance by turnover: Relation between the total cost of maintenance and the turnover of the company in the considered period. This index is of easy calculation since the values, as much of the numerator as those of the denominator, are normally process by the accounting department of the company.
- Cost of Maintenance by the Replacement Value: Relation between the accumulated total cost in the maintenance of determined equipment and the value of purchase of that same new equipment (value of replacement). This index must be calculated for the most important items of the company (that they affect the turnover, the quality of products or services, the security or the environment), since it has been indicated, is customized for the item and uses accumulated values, which it is highly time consuming, not justifying to be used for secondary or non critical items.

The indices of world-wide class require a parameter that is not simple for calculation, i.e., the maintenance cost. The way of calculation of this cost demands an absolute consensus for a suitable later comparison of KPIs. The costs model, therefore, does not become an aim in itself, but a tool, by means of the available data, to extract those indicators of financial character that allow the different hierarchic levels from the organization to value in a quantitative way the efficiency of the maintenance function in its financial perspective. The object that is persecuted is the description of a clear, simple model based on a realistic collection of data and a later processing of those data for the preparation of the maintenance indicators and in particular the financial ones.

The model will have to differentiate and to select to those considered costs “hard” or “soft” based on the indicator to generate and of the complexity of the data harvesting. “Hard” represents easily measurable aspects and necessary information for the required processing can be extracted. On the other hand, “soft” represent an intangible or more complex measurement, [7]. Indicators “soft” like the cost of not to have realized determined formative action, or the non availability of a CBM (Condition Based Maintenance) equipment that an anomalous threshold of vibration had detected, are attractive but hardly measurable in the traditional data collection and will be necessary to look for those costs “hard” of easier operation and than they contribute the required information.

2. The economic objectives of maintenance function

The maintenance function has the mission to maintain the equipment of the company in good condition of operation with a reasonable cost, i.e. the desired efficiency with the determined effectiveness. This should be analyzed from two points of view concerning the equipment and machines:

- Management point of view when deciding upon the installation of new equipment. The decision criterion will be the one of the total cost of the equipment by production unit, which is the relation of the total cost of the equipment, including its acquisition and maintenance, with respect to the amount produced in the life of the asset.
- Production point of view related to the people in charge of the management of the equipment. In this case, the equipment exists, and their owning expenses and the production program are well known data. Then the decision criterion will be the total cost of maintenance that will be made up of the loss of benefit that will undergo the company as a result of the breach of the program of production caused by the failure of the equipment (failure cost) and of the cost of the operations of maintenance, that includes three elements: (1) The cost of operation of the units of the company in charge of the repair operations (tools, equipment, personnel of all categories), (2) the cost of the pieces and spare part consumed besides its expenses of acquisition and storage (replaced more financial costs) (3) the cost of operations subcontracted with outer specialties.

2.1 The Global Cost of Maintenance

The global cost of maintenance is defined as the value that accumulates the economic result of the total management of the maintenance of a company. A machine, installation, section, plant or factory, which has a high cost, illustrates the management of maintenance is inadequate or the condition is unacceptable it requires large sums of money to obtain the desired effectiveness. On the contrary, if the cost is low, a good management of maintenance is performed as long as the asset fulfills the effectiveness demanded by the plant.

The Global Cost represents in an integral way all the aspects of the maintenance in benefits and losses in a company are shown. The following figure illustrates each one of the components. Figure 1 represents a complete scheme of the global cost with the concepts previously defined.

One of the primary targets of this work is the proposal of a model to calculate the global cost. [8] proposed a model of costs that consists of a generalization of a structure of decomposition by levels "Work breakdown structure", (WBS), to be applied in the different processes and all the areas of the supply chain. This model has been adapted to the maintenance process to achieve the successful calculation of Global Maintenance Cost. The model shares with other models the premise of reflecting the process and their activities in the costs, analog to Activities Based Costing (ABC), analyze the activities associated to the targeted process, and following the model of costs based on processes, the process under study, with its all factors, are described with an expression where all involved costs are quantified. This analysis will become the tool to generate the financial indicators due to the capacity of harvesting "hard" parameters.

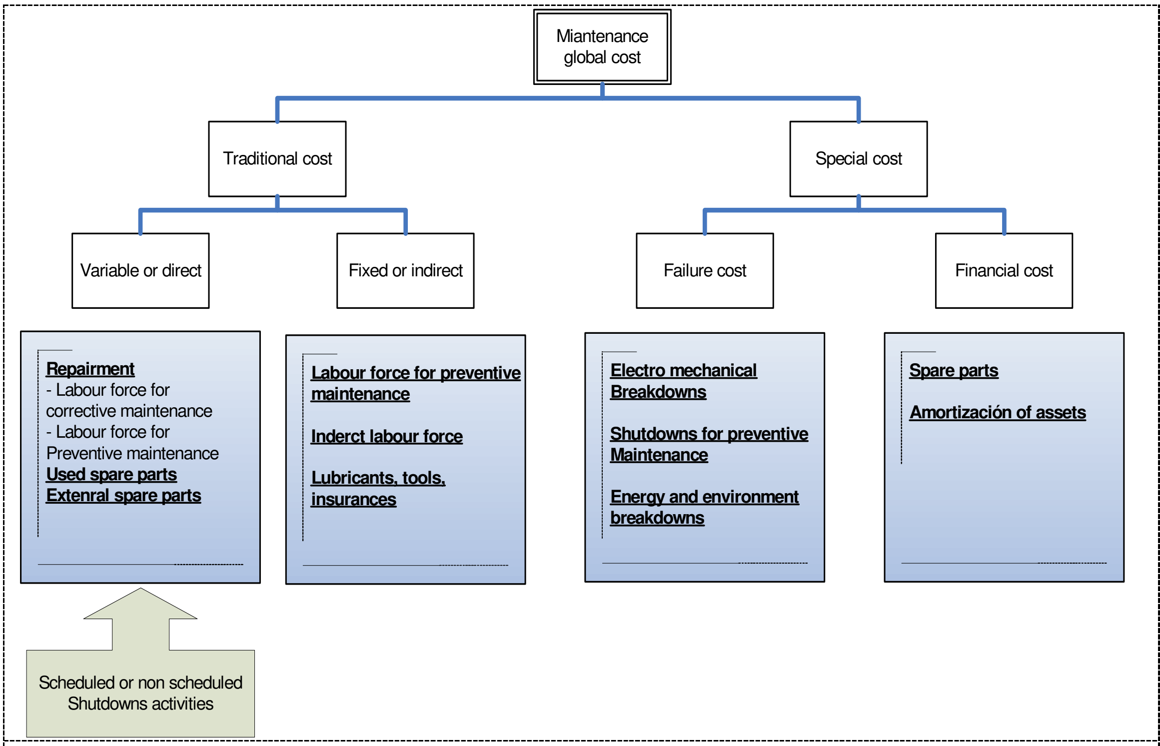

Figure 1. Breakdown of Maintenance Global Costs in its different concepts.

3. Calculation of the global cost of maintenance

According to AFNOR (1994) the global cost of maintenance C_g is the addition of tour components:

- Cost of intervention (C_i);
- Cost of failure (C_f);
- Cost of storage (C_a);
- Cost of over investment (C_{si}).

$$C_g = C_i + C_f + C_a + C_{si} \tag{1}$$

This global cost can be calculated for a concrete machine, group of machines or whole plants in order to fulfill methodologies such as Reliability Centered Maintenance (RCM) that rationalize the observance and application of the maintenance in those equipment that more affects to the given cost their criticality or matters.

3.1. Costs of intervention

The intervention cost (C_i) includes the expenses related to the preventive and corrective maintenance. It does not include costs of investment, or those related directly to the production: adjustments of production parameters, cleaning, etc...

The intervention cost can be decomposed in:

- Internal or external manpower,
- Stock spare parts or bought for an intervention;
- Required expendable equipment for the intervention;

It is important to give a realistic value to the costs of intervention by unit of time ci and hour-man because they influence directly in the global cost of maintenance, the objective function to diminish.

3.2. Costs of failures
These costs correspond to the losses of margin of operation due to a maintenance problem that has produced a reduction in the production rate of products in good condition. The loss of this margin can include increase of the operation costs or a loss of business.

The maintenance problems happen by:

- Preventive maintenance badly defined;
- Preventive maintenance badly executed;
- Corrective maintenance badly executed, i.e. conducted in very long terms, realized with bad spare parts or of low quality.

It is important to stress that the cost of failure of the equipment corresponds to the losses of operation margin; the cause is a defect that brings about losses of production of acceptable quality.

The failure cost can be calculated with the following formula:

C_f = income no perceived + extra expenses of production - not used raw material

The components of this cost are:

- Income non perceived: This factor will depend on the possibility of recovering the production in diverse schedules, weekends etc. In case of being a continuous production, evidently there is no capacity to recover the losses, reason why the production of that time slot and the associated incomes should be imputed in this item.
- Expenses extra of production: In case it is possible to be recovered part of the production in temporary slots will have additional costs which are the following:
    - Necessary energy for the production;
    - Raw materials;
    - Fungibles;
    - Expenses of services such as quality, purchases, maintenance, etc.
- Not used raw material: It will be a factor that in case of not being possible to recover the production. It will be subtracted from the failure cost, because at least it has not been incurred the consumption of that raw material that if will be consumed if the productive plan is recovered, maybe with some cost overrun of storage, transports or degradation (unless it is perishable product that there is to throw case of not processing).

The most common model in the estimation of the calculation of failure cost when there are productive assets that assume total or partially the tasks of the assets under maintenance is Vorster & De la Garza [9].

3.3 Cost of storage
The inventory represent approximately a third of the assets of a typical company, according to several authors including Diaz & Fu [10], extending this praxis to all type of business, is industry or service apparently is a highly repeated landlord. In fact the model of costs more extended and validated is that in maintenance, 70% of the budget is manpower and 30% are spare parts. The storage cost represents

the costs incurred financing and manipulating the necessary inventory of spare parts and consumptions for the maintenance function.

3.4 Cost of over-investments
When designing the plant, the correct decision is the one that diminishes the global maintenance cost of the asset during its entire service life. It implies generally, that equipment is bought with initial investments bigger than fulfill the same requirements in terms of productivity, but whose maintenance costs of associate intervention and storage are considered cheaper. In order to include the overinvestment, the difference is amortized during the life of the equipment. Thus it is possible to punish in the global cost the extra investments required to diminish the other components of the cost.

Similarly, the indiscriminate application of expensive technologies and methodologies like monitoring of non-necessary parameters of condition can be considered over investments and burden the maintenance budget enormously. Finally, all investments on the assets which awaited return is not obtained should be charged in this category

3.5 Avoided costs
One of the most frequent problems when modeling financially maintenance systems is that the original costs have been modified several times in successive applications of methodologies or technologies that looked for the reduction of the global cost on the basis of costs what is called avoided.

In the indiscriminate implantation of policies of reduction of costs, three of the four parameters that constitute the global cost are affected:

- Costs of interventions (C_i): Normally these are reduced in frequency and in volume then most of the predictive technologies secure a smaller aggressiveness in the failures with a reduction of corrective and an increase of the preventive ones.
- Costs of failures (C_f); Reduced in determined predictive policies where complete overhaul are replaced by small inspection which usually are performed without stopping the process.
- Cost of over-sized investments (C_{si}): Perhaps, useless expensive equipment and plans of inspection are the most noticeably item in this cost because budget is increased but rarely are used and in consequence no added value to the process itself

In the following equation one can see the impact of the costs avoided with their double dimension, i.e. when a technology or concrete methodology implies an investment. That is to say, the cost of intervention and failure will be reduced with the application of the chosen technique intervention in a percentage, however, in the same way, the cost of overinvestment will increase if implanted technique is not interesting for the company and therefore it does not result in a return of investment.

$$\begin{aligned} C_g &= C_i + C_f + C_a + C_{si} - C_{av} \\ C_g &= (C_i - C_{av\_i}) + (C_f - C_{av\_f}) + C_a + (C_{si} + C_{av\_si}) \end{aligned} \tag{2}$$

4. Model of maintenance costs
The proposed model to obtain the total cost of maintenance is a full costing approach, with the differentiation between direct and indirect costs. This model is adapted to the above mentioned global cost, with its four components, as the constituents elements of full costing.

$$C_g = C_i + C_f + C_a + C_{si} \tag{3}$$

Among the previous components, there is no doubt that the three last ones correspond inexorably to direct costs, being the cost of failure the most relevant one and simultaneously the most difficult to be quantified.

The warehouse cost is a direct cost of the maintenance function, because the election to save huge amounts of expensive spare parts implies a higher cost on the repairs, and in fact it will more directly affect to the maintenance cost center due to the capital invested in spares parts stock. Finally, the overinvestment cost is a related to the election of the equipment; an election to invest more in an equipment than in another one, with the hope of fault costs reduction due to the incurred extra investment.

Therefore Cost of intervention remains as unique element that agglutinates part of direct and indirect costs on the one hand, absorbing the visible part of the intervention, and on the other hand the indirect expenses supported by the maintenance function: these indirect costs will be later on imputed in its ratio of monetary units per hour of intervention.

$$C_g = C_{Direct} + C_{Indirect} = C_i + C_f + C_a + C_{si} =$$

$$= C_{i\_Directo} + C_{i\_indirecto} + C_f + C_a + C_{si} \qquad (4)$$

The indirect costs of intervention will correspond to:

$$C_{i\_indirect} = c_{i\_indirect} T \qquad (5)$$

Being T the number of required hours man for the intervention and $c_{i\_indirect}$ the coefficient of monetary units per hour imputed of indirect costs to maintenance.

$$c_{i,t} = \frac{\text{Total indirect costs charged to maintenance}}{\text{Total intervention time}} \qquad (6)$$

This value evidently must be determined and negotiated previously at the beginning of the process, so that it does not cause an excessive burden, because in ordinary productive plants the factor of more relevance is the failure cost and very high indirect costs which eventually would increase the inefficiency of the maintenance department.

Therefore and according the model of Lambán et al. [8]:

$$C_g = C_{Direct} + C_{Indirect} = C_{Mat} + C_{Op\_proc} + C_{Op\_ext} + C_{Moi} + C_{Gest\_proc} + C_{Gen} \qquad (7)$$

Where

$$C_{Direct} = C_{Mat} + C_{Op\_proc} + C_{Op\_ext} \qquad (8)$$

$$C_{Indirect} = C_{Moi} + C_{Gest\_proc} + C_{Gen} \qquad (9)$$

Being for the global cost:

- $C_{Indirect}$ a part of the cost of intervention in utilized man hours

- $C_{Op\_proc} = C_{failure}$ i.e., the operational costs of the own process of maintenance, the originated by the absence of productive capacity will be imputed The costs are the most relevant due to high amount of money involved and its complexity of calculation. Many authors have dedicated special efforts to this matter, being the most common and popular in application the method of Vorster & De la Garza [9].
- C_{Op_ext} Outsourced overhauls, predictive inspection and non-destructive testing, are some of the typical costs imputed normally in this section.

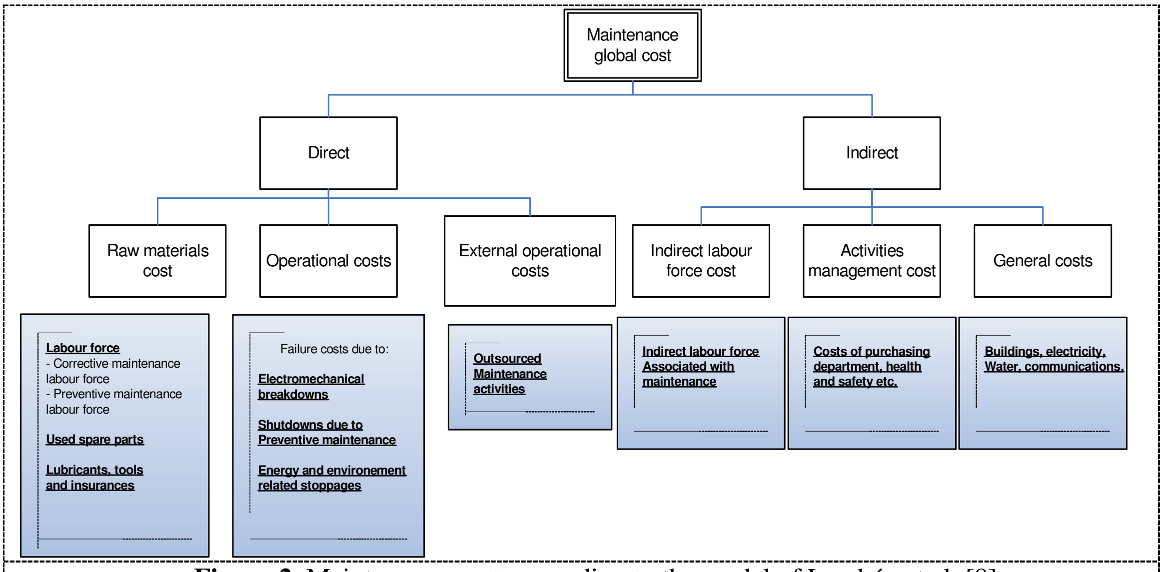

Figure 2. Maintenance costs according to the model of Lambán et al. [8].

5. The maintenance model of costs and balanced scorecard

The model of costs shown is oriented to sustain the fast generation of the financial indicators. But these are not the unique ones destined to the measurement of the performance of the maintenance function, since there are tons of maintenance indicators related to the people, RAMS parameters etc… reason why the available set of measures has grown noticeably and it is extremely convenient its hierarchical classification according to different types from arrangements. The most extended is the adoption of the Balanced Scorecard by Kaplan & Norton [11]. Adaptations of BSC to maintenance, like the one of Galar et al. [12], promote the financial perspective among the four existing where the model of costs plays a fundamental role.

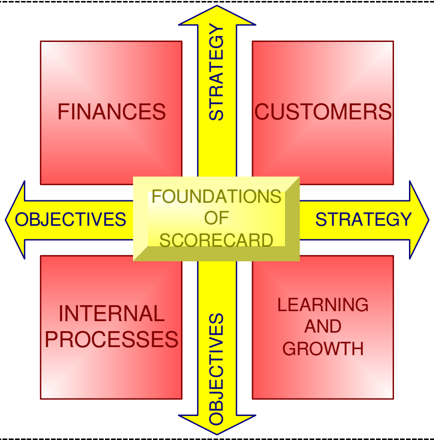

Figure 3. Interrelation between objectives strategy and perspective of the balanced scorecard.

The financial perspective has been the one traditionally developed and used by top managers or company high level positions. When applied to maintenance function, it is based on two primary objectives, which unite to secure the balance between the demanded effectiveness and the desired efficiency. That balance is achieved through the attainment of the following goals, to improve the availability and to improve the associate costs as can be observed in figure 4:

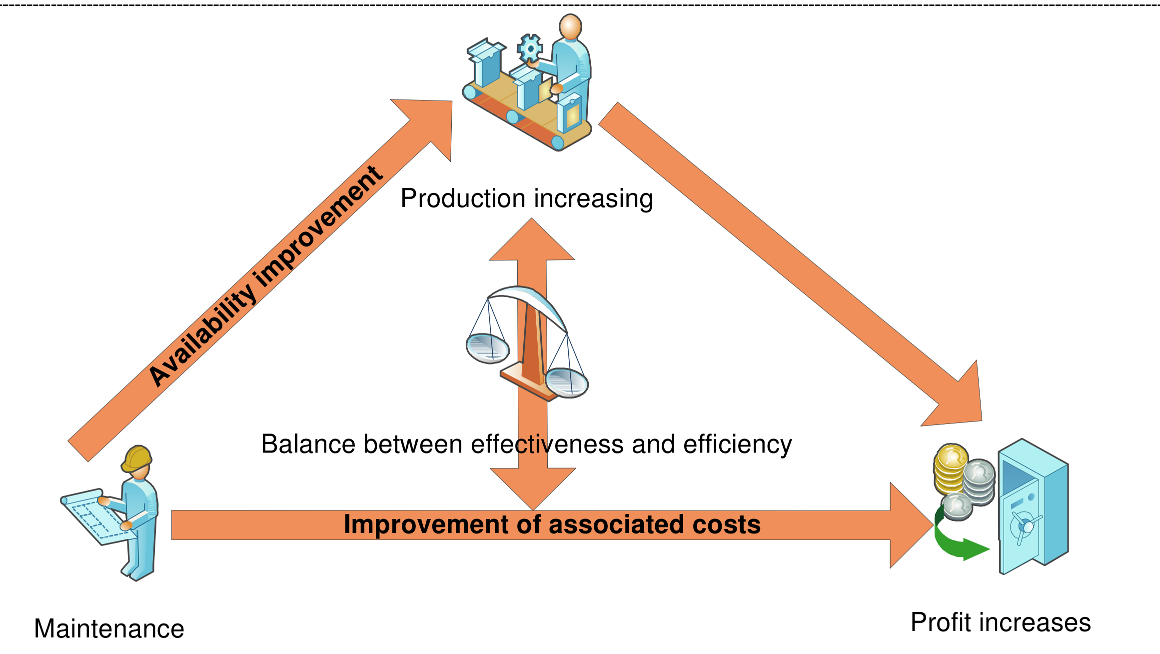

Figure 4. Balance between effectiveness and efficiency in the financial perspective.

This work will focus in showing the indicators when the goal pursued in the company is the improvement of the costs associated to the maintenance

5.1. The objective of the costs improvement

This objective tries to balance and fit the costs of maintenance with the profit of the availability necessary to fulfill the requirements of production or operation, i.e., the objective is to look for with the smaller possible cost the level of necessary availability. This index has to be observed in a temporary tendency. Thus, for a period i it will be:

$$\frac{\text{Total maintenance costs}}{\text{Demanded availability}}$$

5.1.1. To agree the content of the maintenance costs. The model of costs and the poor tradition in its usage in the maintenance function show intangible and hidden aspects in most of the costs imputable to this department, the reason why different interpretations arise and completely different ways of calculation can be found in very similar manufacturing environments. It is for that reason that the maintenance headquarters must now the rules game, i.e. how they are going to analyze the costs, under which parameters, what is going to be charged in order to have the control on those things that are going to be of their responsibility. The following indicators mark the relation of the costs of maintenance with respect to the manufactured end item, to the secured availability or the value of the machinery. They are the great corporative numbers that are used in the highest levels to define the great changes in the policies of manufacture and by extension of maintenance.

The numbers to be handled by the top management with respect to maintenance must be reduced, no large sets, but they should contribute with excellent information for a proper decision making. The budget of maintenance with respect to the replacement value of the assets is an indispensable element in the decision of renovation of equipment or even of delocalisation of plants. Equally, the relations of maintenance with respect to the manufactured product or to the cost of that manufacture, they will present/display all the scenes in which is present maintenance.

$$IE1 = \frac{\text{Total Maintenance Cost}}{\text{Assets Replacement Value}} \tag{10}$$

$$IE4 = \frac{\text{Total Maintenance Cost}}{\text{Production transformation cost}} \tag{11}$$

$$IE3 = \frac{\text{Total Maintenance Cost}}{\text{Quantity of output}} \tag{12}$$

For the directors of factories or operations departments, excellent ratios are the referring ones to the availability with respect to the production, facing quantifying suitably that amount I can process in the up time that maintenance obtains.

$$IE6 = \frac{\text{Availability related to maintenance}}{\text{Total Maintenance Cost}} \tag{13}$$

$$IE5 = \frac{\text{Total Maintenance Cost} + \text{unavailability costs related to maintenance}}{\text{Quantify of output}} \tag{14}$$

It is in this case where the complexity of the failure cost is shown being this second aside from the IE5- numerator agreed model of costs prevails like necessity for the suitable generation of this indicator for quantifiable objectives.

The budget destined to the different types from maintenance with respect to the total budget will be the data that the maintenance director handles, on the basis of which he will have to make the decisions to transfer budget among maintenance types, looking for that new combination contributes an improvement in the availability secured for the client.

$$IE15 = \frac{\text{Corrective maintenance cost}}{\text{Total Maintenance Cost}} \tag{15}$$

$$IE16 = \frac{\text{Preventive maintenance cost}}{\text{Total Maintenance Cost}} \tag{16}$$

Indicators such as IE15 and IE16 proposed by UNITE 15341 [13] are examples of costs where an agreed cost model is essential to succeed in their calculation. It should be highlighted that in the costs contemplated by the standard, the indirect ones are included but the ones produced by non availability are excluded, so the standard clearly claims for hard costs fleeing running away from the difficult quantification of the failure costs.

Concerning planned maintenance, the indicators proposed by the standard are the enumerated ones below. All of them have a high percentage of intervention costs with the corresponding part of indirect costs but weighing plus first. Even, the indicator IE20 related to the scheduled shutdowns for maintenance does not even consider the dismissed profit produced due to these stoppages but it quantifies only the interventions produced in that temporary interval.

$$IE17 = \frac{\text{Condition based maintenance cost}}{\text{Total Maintenance Cost}} \tag{17}$$

$$IE18 = \frac{\text{Predetermined maintenance cost}}{\text{Total Maintenance Cost}} \tag{18}$$

$$IE19 = \frac{\text{Improvement maintenance cost}}{\text{Total Maintenance Cost}} \tag{19}$$

$$IE20 = \frac{\text{Maintenance shutdown cost}}{\text{Total Maintenance Cost}} \tag{20}$$

6. A model to measure the performance

The benchmarks and references for the maintenance performance measurement are often contradictory and almost always specific of the industry in which they were created. It is convenient to define a generic procedure, to align logically the efforts of a department of maintenance with the objectives of its company. Therefore it is possible to outline the procedure in its totality through a flow chart (figure 5).

The model is deliberately not specified for an industry or sector, thus ensuring their generic nature and their use may be broader. Following this process, a company should be able to reflect on how best to ensure the integration of the maintenance function and business needs. Goal setting in a hierarchical order is called to ensure that all functions within the company work together. Williamson [14] describes how the maintenance is not a department but a shared responsibility. This concept will undoubtedly become increasingly common. This conception of maintenance reinforces the idea that all functions within the company, properly aligned and working together, are based on hierarchical control panels. The ultimate goal of the cooperative work of these functions will improve performance and reduce costs, i.e. a quantitative improvement of effectiveness and efficiency.

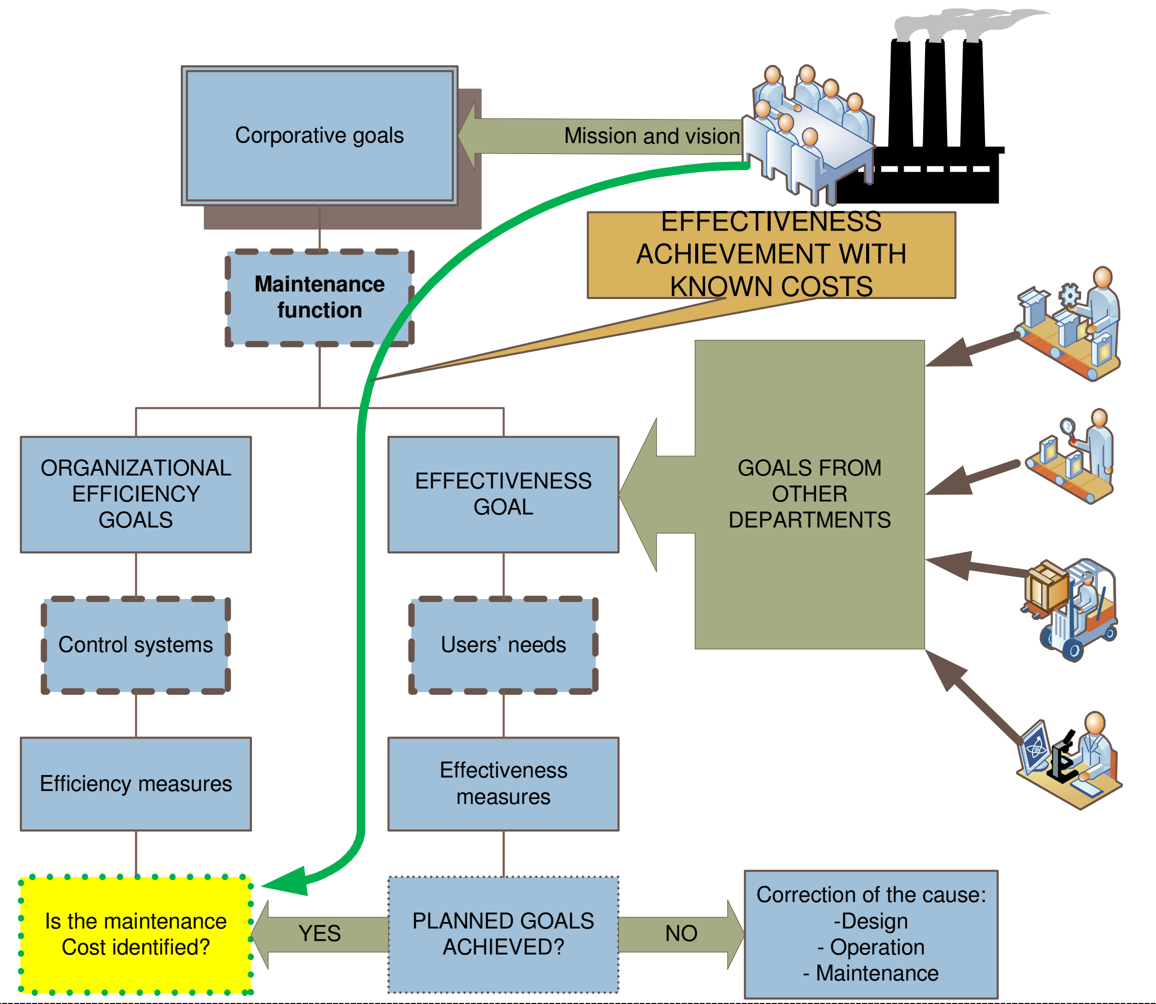

Figure 5. Model to measure the maintenance performance.

The propose methodology, demonstrates that a breach between the effectiveness of the maintenance and the organizational efficiency exists. An importance factor resides in the minimum threshold of the costs associated with the effectiveness of the maintenance function. The main reason is that the global costs are in fact one combination of both joint of objectives (effectiveness and efficiency). This demonstrates that the total cost of maintenance is in fact the sum of the maintenance effectiveness and the costs caused by inefficiency. Therefore, it is deduced that the cost is a vital bond that entails together objectives both.

It is possible to be intuited that the objective and the measurement of higher level than must be the guide of a maintenance department is the reduction to the minimum of the associated total cost to the function. Or to be more specific, the fulfillment of all the objectives and goals to a minimum cost, according to expose Mitchell [15], with the purpose of maximize the productivity.

6. Conclusions

The problems of maintenance performance measurement are common and similar in organizations. Although the solution to each of them inevitably varies from a plant to plant the true causes of the complications tend to be similar.

Once the role of the maintenance function in an organization is defined, it is possible to propose objectives to be fulfilled and the required measures to monitor that fulfillment. The objectives and the measures must constantly be evaluated and be reviewed so that they can remain aligned with the enterprise needs. It is important to align the measures with each one of the primary targets. It does not have sense to determine an objective to improve the performance if it suitably does not go to be controlled or to be measured.

The indicators related to the organizational efficiency tend to be difficult to measure due to their subjective character. For that reason that the top managers tend to concentrate in the costs related to resources committed and consumed (i.e. the costs "hard" derived from the efficiency of the maintenance). These are much easier to be measured with the use of systems CMMS, programmed to capture this type of information through the management of high volumes of working hours, purchases of spare parts, contractors etc. This tendency, has influenced in which the indicators more commonly used for organizational aspects make reference to use of personnel, working hours or percentage of direct or indirect personnel by the underlying complexity in the measurement of intangible aspects bound to the costs "soft", like capacities of reaction, abilities or facility of work in teams.

For that reason in this work a series of indicators is set out so it will be possible to verify the eventual improvement of the maintenance costs of a company. In addition, a cost model is proposed to increase the accuracy in the calculation of the indicators.

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