PREVENTIVE MAINTENANCE PLANNING USING QUALITY FUNCTION DEPLOYMENT – QFD

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***Abstract* - The QFD has been used for product development for a long time. Nowadays, at the current level of maintenance, we used the QFD to innovate in the prioritization of assemblies and subassemblies that must have their planned maintenance. To achieve the proposed objectives, we firstly reviewed the literature, then analyzed the maintenance data of a production line, calculated the correlation between the needs of the sector of production with each subset of equipment that make up the line, and then constructed the QFD to prioritize the maintenance planning of the most important sets for product quality. The findings showed that the current planning model has a high level of assertiveness on the equipment schedule, but a prioritization using QFD assist in the specification of which subset undergoing maintenance, increasing the availability and reliability of equipment. The results showed there was an increase of efficiency from 79.25% to 83.76% in one year.**

***Keywords*— Maintenance planning. Innovation. QFD. Competitiveness.**

I. INTRODUCTION

To a production system operate without waste and being profitable, the maintenance system should acts effectively. For Khan and Darrab (2010), the maintenance should go beyond repairing problems, but provide quality and productivity control. This is necessary because maintenance is increasingly being treated as strategic for companies, since the high investments in organizations should generate profits. And, the best way to keep the equipment operating is managing its maintenance.

The maintenance sector undergoes a change of concept. Previously seen as support sector, it is currently treated as strategic, since to meet the expected results, the machinery and equipment must meet the expectations and plans made. Maintenance, with a strategic vision for a competitive environment, becomes to look not only for the recovery of damages, but also to the quality and productivity, interfering in the organizational outcomes (Otani and Machado, 2008). Maintenance activities have become increasingly important because the productive efficiency depends directly on the condition and reliability of equipment. Thus, in view of globalization, maintenance becomes focused on the vision of Quality Management and Productivity, so the maintenance department plays a vital role in the functioning of an industry.

The best known maintenance types are the corrective and preventive. For Sachdeva *et al.* (2008), corrective activities are characterized when the main action is to restore the basic functional capabilities of an equipment or repair some failure that he suffered; also being called the maintenance of reaction. On the other hand, the preventative maintenance can be, according Meselhy *et al.* (2010) divided into two groups: maintenance time-based and maintenance based on the condition. In the current context, where flexibility and reliability arise as differentials, comes up new methods of managing maintenance such as maintenance centered in reliability, a methodology used to determine which preventive maintenance is required to maximize confidence in equipment and in the system (Khanlari *et al*., 2008).

It has been observed that traditional methods of maintenance planning partially supply the needs of business. The corrective maintenance should be employed only in cases where preventive and predictive maintenance becomes costly, but it brings along the risk of downtime and unexpected drop in production. For Karim *et al.* (2009), this risk pulled the development of different maintenance methods in recent years, in order to manage the complexity generated by the technological maintenance equipment. Two examples of maintenance methodologies are Reliability Centered Maintenance – RCM and Total Productive Maintenance - TPM. Currently, one of the most accepted method is the RCM, used to ensure confidence in the equipment (Khanlari *et al.*, 2008).

Many maintenance tools and methodologies have been used and tested in maintenance management. Söderholm *et al.* (2007) present some: standardization, Failure Mode and Effect Analysis – FMEA, Overall Equipment Effectiveness – OEE, decision tree, risk analysis, Total Productive Maintenance, Reliability-Based Maintenance, and others. To Pun and Nurse (2010) maintenance strategies can be divided into two classes: the ones that follows a logical and scientific planning, with control and perform analysis; and the others without prior definitions. This paper proposes the introduction of the Quality Function Deployment - QFD, traditional tool for development of product design, to plan the preventive maintenance of a metallurgical company located in Southern Brazil. The QFD was chosen because it is a prioritization tool that makes explicit the relationship between customer needs, represented in this study by the production line, and the quality of the product and the parameters of equipment maintenance. Using QFD, the planning of preventive maintenance becomes easier to allocate maintenance tasks on equipment and assemblies for the most important product manufactured on production lines.

The methodology QFD was adapted to the characteristics of equipment and products manufactured, in a production line that works twenty-four hours a day, during six days per week. Thus, the main data collected were the requirements for product design and the relationship between these subsets and the equipment of the production line. With these data we built the "house of quality" for the maintenance of the production line, identifying the major assemblies and subassemblies of equipment that most influence the final product quality. From this analysis, we expected to prioritize the actions of the planning and the maintenance management at these points.

II. METHODS

A. Quality Function Deployment - QFD

QFD is a technique for product development and a proven methodology for achieving customer satisfaction. It can either be applied to the development of education and training (Ermer, 1995; Zairi, 1995 apud Chan *et. al*., 2009). The central idea of QFD is to establish the necessary control before starting the production, so the product quality can be ensured in the planning phase (Chan *et al.*, 2009). Utne (2009) describes the construction process of QFD as involving the construction of one or more matrices linking the organization's priorities and the consumer’s needs. These matrices are called “house of quality”.

Some researches using QFD in activities different from the traditional products developments are being exposed. Melo Filho *et al.* (2010) highlighted the work of Chakraborty and Dey (2007) and Almannai *et al.* (2008).

The QFD was developed by Yoji Akao in 1966. It is a method for developing quality projects that satisfy the consumer, leading their needs to the designers. Moreover, we reinforce that QFD, when applied correctly, can help to reduce the time of product development (Akao, 1990). For Chang and Wu (2002) QFD has become popular due to its availability of trainings, consulting, software and access to the literature.

QFD can bring many benefits to organizations. Mehrjerdi (2010) points out some: it supports decision-making between customer demands and what the supplier can provide; it helps to improve the teamwork between engineers and the rest of the department; and it can increases customer’s satisfaction and may reduce the time to customer response.

B. QFD in the maintenance management

Macchi and Garetti (2006) report expressive differences in the selection of an optimal maintenance policy. These differences are due to the decision made, which can be based on the level of the equipment or by the systemic analysis of the production process. To Carnero and Delgado (2008), if inefficient results are obtained for a maintenance performed, it should be made a list of possible improvements that could be implemented by the organization to achieve the desired efficiency. In some case, it is necessary to define a new way of monitoring the performance of maintenance. Muchiri *et al.* (2010) stresses the importance of choosing the maintenance strategy. Also, the strategy should consider the design specifications of the equipment, which cannot be exceeded, with penalty of generating operational problems. With such care, according to Mehdi *et al*. (2010), the levels of product quality and production flexibility could be achieved.

Considering the maintenance as a service, internal or external to the organization, QFD can be used in planning the activities of the maintenance sector. To Andronikidis *et al.* (2009) QFD provides a structure that helps to guarantee service quality and customer satisfaction.

C. Methodology for innovation in preventive maintenance planning using QFD

The main goal of an organization is to increase the profit of their activities. According Khanlari *et al.* (2008), management and maintenance strategies can leverage profits in two ways: reducing operational costs and increasing productive capacity and operational availability. The total cost of maintenance must be controlled and depends on the quality of equipment, how they are used and the way maintenance is managed. Besides the profit, it is necessary to meet the needs of their partners and the community (Cheng and Melo Filho, 2007)

The company studied is a manufacturer of many differentiated products, and the production line analyzed is one of the responsible for a high technology product, being the only company in the South Region of Brazil to own this kwon-how. Therefore, adopting the idea of Sachdeva *et al.* (2008), as the age of equipment increases, there is a progressive growth in the failures rate, so preventive maintenance programs becomes as important as the decision to perform maintenance. It is proposed that the decision to prioritize sets and subsets at the time of maintenance planning is performed based on a relationship between the equipment and product. Consonant with this idea, a production process subject to deterioration with increasing failure rates produces a greater quantity of items not in accordance with its requirements (Medhi *et al*., 2010).

Thus, we have chosen the QFD tool to prioritize which pieces of equipment are most influential to the characteristics of their products. This work is characterized by an applied research, with the inductive method. To conduct the study, we adopted the case study, which according to Gil (2010) the study has the advantage of simplifying the analysis, evaluate the totality of variables and motivate new views on the subject studied.

Taking into account that the QFD aims to identify and prioritize customer needs and translate these requirements into appropriate care to the demands (Burke *et al*., 2002 apud Shiu *et al*., 2007), we considered the manufacturing process as the client of maintenance process, and quality requirements of external customers and technical specifications as the technical variables to be achieved during the production process for the construction of relationship between quality requirements and internal customer needs. Thus, the relationship between the processes is shown in Fig. 1.

Similar to Cheng and Melo Filho (2007), for each requirement of product quality that meets the needs of final clients, the maintenance planning team should identify the operating characteristics of the equipment to meet the requirements of product quality. To this, we realized a brainstorming, listing all the requirements of quality evaluated, the requirements of final customers, and the needs of the production process. With a list drawn up, it was set up with assistance from the software "Casa da Qualidade" © version 1.3, the house of quality for the maintenance of the production line studied.

The "Casa da Qualidade" software has a simple operation. To relate the variables, it is necessary to include the consumer's needs with their values. Then, it is included the quality requirements. With these data, it is assigned values to represent the intensity of relation between them. These values can be: strong (●), weighing 5; medium (◉), weighing 3; weak (○), weighing 1 or no relation, weighing zero.

The fulfillment of the roof is made relating the quality requirements with the options: strongly positive (⊕), 5; positive (+), 1; none (0); negative (-), -1 and strongly negative (⊖), -5.

Whereas the production line has five major equipment and four auxiliary, it was determined the main quality characteristics of each. The caption "A" deals with the auxiliary processes and the legend "P" the main processes, as shown in Table 1. For all processes, it was identified the Quality Requirements – "RQ, based on assemblies of each equipment and on its importance for the quality of the product.

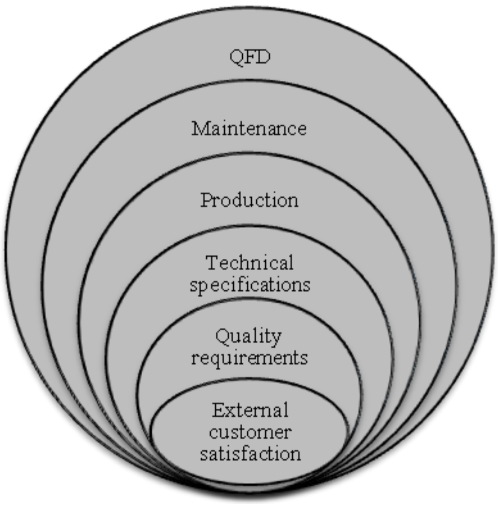

Figure 1. Relation between the processes of maintenance management and customer satisfaction.

Table 1. Stages of the process and quality criteria

Stages of the process	**Quality requirements**
A1	RQ 1
P 1	RQ 16, RQ 15, RQ 14
P 2	RQ 9, RQ 10, RQ 11, RQ 12, RQ13
P 3	RQ 8
A 2	RQ 6, RQ 7
P 4	RQ 2, RQ 3, RQ 4, RQ 5
P 5	RQ 2, RQ 3, RQ 4, RQ 5

The next step was the assignment of quality characteristics related to each quality requirement listed above, thus building the house of quality. This house faces the quality requirements in relation to requirements of customers, ranking them in degree of importance, unfolding the characteristics of quality and systematizing the characteristics that maintenance should prioritize during the planning of preventive maintenance. Moreover, it helps to understand the characteristics that are desired in the final result of the maintenance process, determining the functions that the equipment must perform to the manufactured product meets the quality requirements and customer needs.

To construct the QFD diagram, the items classified as consumer needs could be divided into three hierarchical levels, but in this study we adopted the classification in one level. To use the QFD to prioritize maintenance, we placed as consumer needs all characteristics of the *output* of the production process. In items that relate quality requirements, it was inserted the data related to subsets of each equipment. With these two data it was evaluated the degree of relationship between customer needs and quality requirements.

In addition to these data, it was still ranked the "consumer value" of the service, a value between zero and ninety-nine; according to how important each output requirement is to the production process. To define which subset should be prioritized, we used Eq. (1).

$$\sum_{i=1}^{n} v_c g_r \qquad (1)$$

such that v_c is the value of the consumer and g_r is the value assigned to the degree of relationship between customer needs and quality requirements.

Considering the reclassification requirements according to the roof of the house of quality, we used Eq. (2), based on Ogliari (1999).

$$\sum_{j=1}^{n} \frac{p_i p_j}{p_i + p_j} gr_{ij} \qquad (2)$$

where n is the number of design requirements; j is the j-th requirement relating to the i-th requirement; p_i is the weight of the i-th requirement obtained by traditional method; p_j is the weight of the j-th requirement obtained by traditional method and gr_{ij} is the degree of relationship between the i-th requirement and the j-th requirement.

D. Results

To evaluate the benefits of using QFD in planning the preventive maintenance in the production line studied, we analyzed the historical of preventive and corrective

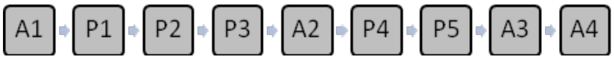

Figure 2. Manufacturing process

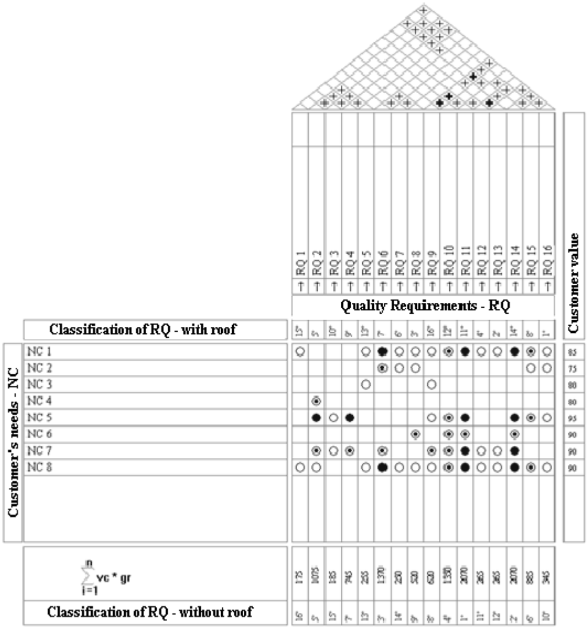

Figure 3. Priorities of maintenance using the QFD. Source: Developed by the authors with assistance from the software "Casa da Qualidade" © version 1.3

maintenance for a period of twelve months, between June/2009 and May/2010, when QFD was not used yet, and between June/2010 and May/2011, now using QFD.

The sequence of the production process is depicted in Fig. 2, which shows the main and auxiliary equipment. The identification is performed with the letter "P" followed by the sequential numbering for major equipment, and with the letter "A" with sequential numbering for auxiliary equipment.

Among the auxiliary equipment, none has undergone corrective or preventive maintenance. The absence of corrective maintenance is considered very good. However, the absence of preventive maintenance may have been due to the periodicity of equipment review and also because they do not influence directly in the manufacturing process, once those are carriers from one machine to another.

The equipment "P 1" was submitted the first maintenance in July 29, 2009, this being an improvement maintenance in the second work subsets and preventive maintenance in the others. On August 27, 2009, the equipment undergone preventative maintenance on the first work subset, which basically tried to eliminate the problems caused on "RQ 15". In the following planned maintenance on September 25, 2010, the second subset underwent replacement of several pieces, but part of the activity was not completed because there were no spare parts. This resulted in rework and machine downtime, reducing its availability for production.

Table 2. Prioritization of maintenance in relation to the quality requirements

Priority	Quality requirements	Tasks
1	RQ 11	P 2
2	RQ 14	P 1
3	RQ 6	A 2
4	RQ 10	P 2
5	RQ 2	P 4
6	RQ 15	P 1
7	RQ 4	P 4
8	RQ 9	P 2
9	RQ 8	P 3
10	RQ 16	P 1
11	RQ 12	P 2
12	RQ 13	P 2
13	RQ 5	P 4
14	RQ 7	A 2
15	RQ 3	P 4
16	RQ 1	A 1

In the same period, the equipment "P 2" went through several maintenance. The first subset has undergone preventive maintenance on June 20, 2009; December 12, 2009 and April 04, 2010. These maintenance replaced the same parts, but part of the equipment has not undergone revision, since in March 27, 2010 there was a breaking in a subset shaft, demanding corrective maintenance.

The second subset of this equipment has undergone maintenance of improvement in October 19, 2009, where it was performed the same changes to better functioning. The subset three, a key to obtaining the necessary quality requirements, has undergone a maintenance for improvement on October 12, 2009, where it was modified the characteristics of a component to better respond to variations in the raw material.

Another subset, important for the timing of equipment, underwent corrective maintenance on April 26, 2010. This was not foreseen in the planning of preventive maintenance, as there is a reserve equipment, but as the break occurred just five days after a shutdown for preventive maintenance, it hurt production. From this, we decided to look at it in the sche dule of stops.

The equipment "P 3", underwent general maintenance on August 03, 2009. The equipment "P 4", which centralizes key business operations that characterize the product according to its specifications underwent a corrective maintenance on June 12, 2009 and preventive maintenance on a subset of secondary operation on May 15, 2010. Moreover, the equipment "P 5", identical to the previous record had no maintenance registered during the period evaluated.

Thus, it becomes quite clear the importance of using an effective technique in the planning of maintenance to check the items that most affect the essential characteristics of the products manufactured at the production line. For the production line studied, the "house of quality" is shown in Fig. 3.

After building the house of quality, linking the needs of the production line, called the consumer's needs, with quality requirements, in this case being the parts of each

Table 3. Prioritization of maintenance in relation to the quality requirements

Priority	Quality requirements	Tasks
1	RQ 16	P 1
2	RQ 13	P 2
3	RQ 8	P 3
4	RQ 12	P 2
5	RQ 2	P 4
6	RQ 7	A 2
7	RQ 6	A 2
8	RQ 15	P 1
9	RQ 4	P 4
10	RQ 3	P 4
11	RQ 11	P 2
12	RQ 10	P 2
13	RQ 5	P 4
14	RQ 14	P 1
15	RQ 1	A 1
16	RQ 9	P 2

Table 4. Average annual performance indicator without and with use of QFD.

Indicator	Without QFD	Using QFD
Efficiency	79.25%	83.76%
Scrap	0.76%	0.72%
Rework	4.60%	2.31%

equipment, came to the result the priority of maintenance presented in Table 2, where it is related the quality requirement to the process of the production line. In this Table the criterion is evaluated without considering the roof of the house of quality, which represents the ratio between each of the quality requirements.

Taking into account the relationship between the quality requirements, the prioritization of maintenance has a slight change, as shown in Table 3. When evaluating this relationship, it shows the influence of each part of a process in the processes and subsets of other equipment. Comparing the traditional model of planning for maintenance, we can see that it includes a larger number of maintenance in the "P 2" and "P 1". The largest number of maintenance in the process "P 2" is due to the higher complexity and larger number of subsets for this equipment.

Using QFD, however, considering the relationship between the quality requirements of a subset of great importance to the process, "P 1", it is observed there was no maintenance during the 12 months using traditional maintenance planning. Applying QFD to prioritize planning, we managed to improve the performance indices of the production line, as shown in Table 4.

It shows that the QFD used in planning of preventive maintenance assists in improving the performance indicator and competitiveness of the company.

III. CONCLUSIONS

The planning of maintenance is effective in dealing with the equipment to be stopped for maintenance. That is, only with a more effective prioritization technique it can be defined the subset undergoing maintenance, since this prioritization should occur depending on the characteristics of the final product and the needs of the sector of production for each one.

This model can still be enhanced, through the implementation of a larger number of applications in other production lines and organizations of different kinds to be validated. After this validation, it is proposed to construct a specific model for computerized prioritization of maintenance.

With the evaluation of specialists in maintenance and the use of the methodology, positive results are expected, such as: removal of the root causes of efficiency problems in production, scrap and rework. Therefore, maintenance planning will be performed using a technique that relates each piece of equipment to all necessities of the productive sector and the quality requirements of the manufactured product, which guarantees a higher reliability for equipment and increased competitiveness for the company.

Finally, it is recommended to the company to adopt the proposed methodology, in parallel with its current system for planning and control maintenance held by effective time machines in operation, to optimize the time available to perform the necessary interventions. Thus, maintenance will be directed to the critical points of operation and the production line will be more time available for production, increasing flexibility and competitiveness in this product.

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