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Integrated model linking Maintenance Excellence, Six Sigma and QFD for process progressive improvement

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1. Introduction

The maintenance organization is increasing importance for companies, as it directly affects other relevant processes leading to customers' satisfaction or dissatisfaction. According to this view, several companies continue to improve their maintenance organization through implementing improvement approaches such as Maintenance Excellence (ME) and Six Sigma. Simply put, the end product of such approach in general is to instil better practice within an organization in order to support its values and strategic objectives, maintain and exceed its competitive position. Despite their role in promoting quality, these frameworks have important drawbacks as improvement models, especially, given the lack of their implementation in manufacturing, their integration into the everyday organizational operations. Although Six Sigma and ME both help build quality into the design stage and they are mutually supporting each other's shortcomings, there are a number of organizations, which are failing to reap the fruits of these two approaches successfully. This could be noticed to the following four common deficiencies:

- They are often too complex to be applied as such by small companies;
- They rarely integrate the interaction between Six Sigma and ME;
- ME is treated as a separate activity of SME business operations;
- The implementation process of the excellence models is under-researched area;

This chapter is situated in a total quality strategy (Yong and Wilkinson, 1999). It discusses the practicality of deploying the QFD as a technique for 'best practice' of synergising ME with Six Sigma. However, our contribution includes two aspects: the first one concerns the extension of the QFD method, usually applied to products and services, in the improvement of the maintenance system. As a result, the performances of the maintenance function are improved in a progressive but complete way; the second one focuses on the integration of both Six Sigma and ME approaches in one model.

In this chapter a new method of progressive improvement (Lazreg and Gien, 2007), which lies within the general scope of a methodology of re-design of the maintenance activity is proposed. In this perspective, the next section describes our Maintenance Excellence Model.
Next, Six Sigma and QFD, which are used in the development of the progressive improvement model is presented. The fourth section discusses the model and provides the method detailing how the progressive improvement model is utilized for selecting an improvement action. In section five, a case study in maintenance activity is presented to illustrate the proposed model. Next, findings and limitations of the case study are considered. Finally, the paper concludes with summary and discussion of the potential contribution of this model and suggests areas for future research.

2. Maintenance Excellence

2.1 Literature review

Operational excellence is a broader program of improvement and sustenance business performance in which quality management is embedded. Operational excellence is synonymous with business excellence and it also encompasses other focused excellence programs such as Manufacturing Excellence, Production Excellence and Maintenance Excellence. According to Edgeman et al., (1999) Business Excellence is defined as:

> "An overall way of working that balances stakeholder interests and increases the likelihood of sustainable competitive advantage and hence long-term organizational success through operational, customer-related, financial, and marketplace performance excellence."

Moreover Edgeman et al. (2005) reported that, the best business excellence model provides an approach for jointly optimizing the resulting simplex of business excellence criteria. The primary purpose of business excellence through their criteria is the regular, rigorous and systematic review of the organizations' approaches. Their deployment identifies the organizations' strengths, weaknesses, opportunities for improvement, and threats to its competitive position. This process is referred to as self-assessment (Conti, 1997).
The ME model sets the framework for challenging critical review of the completeness and effectiveness of any business process or project. Through the ME, the organization seeks to provide a high quality process that acknowledges ME, which supports continuous improvement in the maintenance function and focuses on different areas such as strategy, people, information, practices and business impact aspects of ME. The criteria describe each of these areas in detail. This description includes a generic interpretation of intent in each area. The Maintenance Excellence Criteria (MEC) is considered as the guidelines for evaluating maintenance practices and performances. By using the MEC, enterprises will be able to evaluate their capabilities of maintenance management through self-assessment.
Several ME models are available to measure and support maintenance assessment in organizations. The following models for business excellence, often related with quality prizes, serve as a useful framework within which quality improvement efforts may be integrated:

- The Australian maintenance excellence award (Sirft, 2007) seeks to provide a high quality process, which acknowledges ME, supports continuous improvement in the maintenance function, focusing on people, practices, and the business impact of ME.
- The North American maintenance excellence award (Name, 2007) is an annual program conducted to recognize the organizations that excel in performing the maintenance process to enable operational excellence.
- By the late 1990’s, TPM is well entrenched as a continuous improvement methodology across a wide range of industries. For illustration, look at the number of enterprises that have been awarded the TPM prize by the Japan Institute of Plant Maintenance (Shirose, 1996).
- The cornerstone value of the PRIDE maintenance award (Pride, 2007) is to implement profit-centering practices and attitudes in large and small plant maintenance operations.
- The Shingo prize (Shingo, 2007) is an overall systems model that incorporates all aspects of business operations and processes such as maintenance, repair and in whole.

These models have important limitations, as conceptual models but especially as measurement models (Ghobadian and Woo, 1996). When weights are attached to each criterion, they are arbitrary and do not necessarily reflect the relative importance of each model construct. Therefore, the prioritization of improvement efforts becomes somehow ambiguous. Moreover, Silberman (2001) highlights that, the top three to five ranked items that most respondents have identified, constitute the action plan. Given these deficiencies, a New Maintenance Excellence is developed, presented and discussed in the next section.

2.2 The Maintenance Excellence Model

The definition of the different areas of the maintenance function constituted a first solution of the management and organization of a maintenance service in the SME enterprises. The purpose of our Maintenance Excellence Model (MEM) is to determine where the maintenance organization's strengths are to leverage improvements and identify areas of opportunity to correct. It provides a view of the structure, relationships, processes and people relative to good maintenance practices. More else it strives to attain and maintain optimal equipment conditions in order to prevent unexpected breakdowns, speed losses and quality defects in process.

The MEM model consists of ten distinctive areas (figure 1), each representing a different aspect of the organization. These ten areas are subdivided into areas concerned with what results have been achieved (Results) and areas concerned with how these results have been achieved (Enablers).

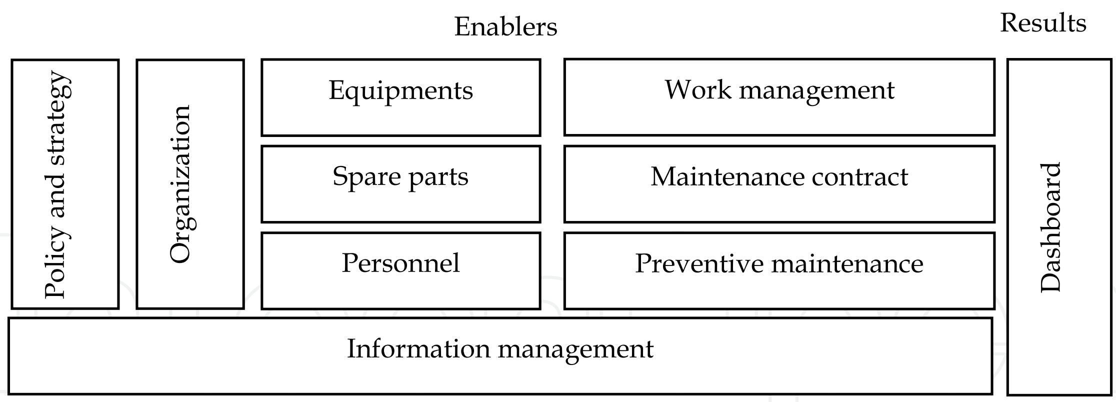


Fig. 1. The maintenance excellence model.

2.2.1 Enabler's and Result areas

Maintenance organizational efficiency depends upon many interdependent variables, which are:

- Policy and strategy: how this introduces an appropriate policy to the objectives? Are these objectives based on the present and future needs and on the information resulting from measures? Are they constantly developed, examined and updated under the control of the responsibility of the service? Does the organization have a real interest in employee's welfare and satisfaction? Are maintenance craftspeople involved in setting and meeting goals and objectives for the department?
- Organization: how does the organization set its mission? Is there a functional organization chart? Are the processes, the tasks and the responsibilities structured? Does the organization help to remove barriers of maintenance craftspeople encounter in their jobs, which they have no control over and, which prevent them from doing a good job? Does the management encourage the maintenance craftspeople and the production operators to work together on certain issues?
- Maintenance contract: are the works of subcontracting recorded? Are the works prepared under constraints of delay and complexity and materiel? Does the service arrange an inventory of all the subcontractors as well as their repartition by activity?
- Personnel: how are the performances of the staff managed? Does good job performance lead to job security in this organization? Have craftsmen received training to help them do their jobs? Do maintenance craftspeople follow safety policies and procedures?
- Information management: how can the supervisor exploit the information coming from the results of activity? How can he/she confirm the results of improvement and their transfer to the various functions of maintenance? Does the organization use a computerized system for maintenance activities? Does the organization update its computerized maintenance system?

- Stores: how are the suppliers as well as the internal and external customers identified? How does the person in charge optimize the stocks cost? Are all inventories accounted for, for example price and lead-time? Are turn-over ratios used for storeroom control?
- Equipments: how is the equipment identified and indexed, in order to recognize its performances? How is the equipment calibrated? How does the enterprise acquire new equipment? How the inventory of equipment is prepared?
- Work management: by respecting its policy and strategies, how does the supervisor manage and improve constantly its processes and increase the service quality? How does the organization use maintenance planner to plan and prepare scheduled maintenance work such as major repairs and shutdowns? Are priorities set for maintenance job tasks?
- Preventive maintenance: does the preventive maintenance program eliminate all unplanned equipment failures? Does the organization try to prevent breakdowns and failures from recurring? How much does the organization track cost (Life Cycle Cost) to maintain equipment?
- Dashboard: how does the service reach its goals according to its forecasts? Which indicators do we have to use and represent the operational results? How do we compare our maintenance service performances with the other competitors?

2.3 Diagnostic approach

2.3.1 Structure of the enablers' area

Referring to the French Standard Agency (Afnor, 1988), which uses evolutionary levels for structuring and organizing the equipment maintenance operations. The author proposes to extend this concept to measure the different enablers. The principal base of the measurement scale, which is proposed in table 1, is based on a constant re-evaluation of the objectives and targets to be achieved as well as a regular re-examination and re-evaluation of the methods carried out (Sonnek et al. 2001). Only an optimal management of all the parameters of the maintenance service allows achieving the goal.

Level	State
0	Anecdotic or without added value.
] 0, 0.2]	Weak performance.
] 0.2, 0.4]	Below average performance.
] 0.4, 0.6]	Average performance.
] 0.6, 0.8]	Very good, effective operations.
] 0.8, 1]	World Class. Best in practice.

Table 1. Measurement scale of the enablers' area

The evolution according to the MEM model is a measurement belonging to one of the six suggested intervals. Each number corresponds to an added value resulting from the equipment management. The value 1 translates the know-how and a control of a particular technology; the value 0 refers to a negligible, marginal and unimportant work. In this context, the measurement of each area state is found by carrying out a comparison between the weight of the current state and the measurement scale.

The current weight of the state of an area A_i is obtained as follows:

$$A_i = \sum_{j=1}^{n_i} a_{ij} \tag{1}$$

The normalized subtotal A_i^{nor} is equal to:

$$A_i^{nor} = \frac{\sum_{j=1}^{n_i} a_{ij}}{5n_i} \tag{2}$$

The total of the enablers' area E^{nor} is equal to:

$$E^{nor} = \sum_{i=1}^{9} \frac{\sum_{j=1}^{n_i} a_{ij}}{5n_i} \tag{3}$$

Where

a_{ij} : value associated to the i^{th} area and j^{th} item

n : number of items by area

n_i : number of items in the i^{th} area

2.3.2 Structure of the result area

From the table 2, the model proposes four intervals and four classes of indicators: the availability of the data and the development tendency and the existence of the internal indicators and the presence of the reference indicators.

The subtotal of the result area Rt is obtained as follows:

$$Rt = \sum_{j=1}^{n_i} a_{ij} \tag{4}$$

The normalized subtotal of the result area Rt^{nor} is equal to:

$$Rt^{nor} = \frac{\sum_{j=1}^{n_i} a_{ij}}{5n_i} \tag{5}$$

The evaluation of the maintenance process in the result area requires quantitative and qualitative data. The results are then financial and operational. They reflect the level of the reached organization and the technology control. To carry out the diagnostic of the result area it is necessary to inventory, for each measurable area, the pertinent and measurable criterion, which determines organization performances. The interpretation of the level "0" should be ambiguous. For example, about the customers' satisfaction item, the level 0 does not involve customers' dissatisfaction. That can say only that the enterprise does not know anything of it and that it does not have any data on this subject (Cua et al. 2001).

[0, 0.25]	] 0.25, 0.5]	] 0.5, 0.75]	] 0.75,1]
Disponibility of data	*Development tendency*	*Internal indicators*	*Reference indicator*
The exact and precise data acquisition requires good and sometimes long preparation, but consequently provides quickly answers to the questions asked in the following phases.	Which tendency can deduce at the beginning from the collected data? This tendency is it positive, unchanged or negative?	Are the objectives of the enterprise achieved? The result is it better, equal or less good than the objective?	How are the enterprise services located in comparison with other competitors?

Table 2. Measurement scale of the «Results» area.

2.3.3 Structure of the "enablers' and result" areas

The competition of the maintenance process in its environment is identified by GT^{nor} indicator, which is expressed as follows:

$$GT^{nor} = \sum_{i=1}^{10} \frac{\sum_{j=1}^{n_i} a_{ij}}{50 n_{ij}} \tag{6}$$

Related to the GT^{nor} indicator analysis, two significant variations are distinguished:

- ***Progress variation*:** it results from the difference between the forecasts of the period (*t+1*) and the achievements of the period (*t*), or the difference between the achievements of (*t*) and the last achievements of period (*t-1*). This variation points out the growth degree of the system and determines its future goals.
- ***Professional gap*:** it is about the difference between the system achievements for one period and those of the competitor for the same period. This variation allows the company to position itself in front of its competitors and to measure its performances as compared to others.

3. Six Sigma

The traditional quality initiatives, including Statistical Quality Control (SQC), Zero Defects and Total Quality Management (TQM), have been key players for many years, whilst Six Sigma is one of the more recent quality improvement initiatives to gain popularity and acceptance in many industries across the globe. Its popularity has grown as the companies that have adopted Six Sigma claim that it focuses on increasing the wealth of the shareholders by improving bottom-line results and achieving high quality products/services and processes. Thus, it is claimed that the implementation of Six Sigma brings more favorable results to companies in comparison with traditional quality initiatives in terms of turning quality improvement programs into profits. Success stories of big corporations that have adopted Six Sigma, such as Motorola and General Electric (GE), have been reported in various papers (Denton, 1991; Hendricks and Kelbaugh, 1998).

Six Sigma was created to improve the performance of the key processes (Bhota and Bhota, 1991). It is a disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them. It focuses on using quality-engineering methods within a defined problem-solving structure to identify, eliminate process defects, solve problems as well as improve, yield, productivity and operate effectiveness in order to satisfy the customer (Wiele et al., 2006).

Many of the objectives of Six Sigma are similar to Total Quality Management (e.g. customer orientation and focus, team-based activity and problem-solving methodology). Thus, several authors suggest that Six Sigma can be integrated into the existing TQM program of the company (Revere and Black, 2003; Pfeifer et al., 2004; Yang K. 2004). Similarly, Elliott (2003) presents the initiative program of the company to combine TQM and Six Sigma and improve the production process and product quality. Yang C. (2004) proposing a coupled approach linking TQM and GE-Six Sigma and using customer loyalty and business performance as a strategic goal of the model. While others suggested integrating Six Sigma with a single quality program, Kubiak (2003) proposes an integrated approach of a multiple quality system, such as ISO 9000, Baldridge, Lean and Six Sigma for improving quality and business performance.

The Six Sigma method for completed projects includes as its phases either: Define, Measure, Analyze, Improve, and Control (DMAIC) for process improvement or Define, Measure, Analyze, Design, and Verify (DMADV) for new product and service development. Knowing that the goal of this chapter is oriented towards the progressive improvement of the maintenance process, the DMAIC approach will be considered in the rest of our development.

DMAIC is a data-driven, fact-based approach emphasizing discernment and implementation of the Voice of Costumer (VOC). It is briefly described as follows:

- **Define** the problem and customer requirements.
- **Measure** defect rates and document the process in its current incarnation.
- **Analyze** process data and determine the capability of the process.
- **Improve** the process and remove defect causes.
- **Control** process performance and ensure that defects do not recur.

The use of the DMAIC method properly can be fruitful to any manufacturing system:

- DMAIC shows how to align the organization through customer-focused measures of performance.

- DMAIC projects are specifically designed to involve all stakeholders.
- A successful organization is one which first puts its customers on its list of priority. If the customer is fully satisfied, then, any organization the world over wins and thus "*never goes bust*".
- Successful DMAIC projects recognize that people and processes are connected in an interdependent system. They achieve significant breakthroughs by striving for measurable stretch goals which span the end-to-end system.
- DMAIC project teams focus their energy on collecting and analyzing data, to slice through opinions and arguments and win collaborative understanding.

4. Quality function deployment

In planning a new maintenance process, engineers have always examined the process and performance history of the current system. They look at field test data, comparing their organization to that of their competitor's field. They examine any customer satisfaction information that might happen to be available (Tapke et al., 1998). Unfortunately, much of this information is often incomplete. It is frequently examined as individual data, without comparison to other data that may support or contradict it. By contrast, Quality Function Deployment (QFD) uses a matrix format to capture a number of issues that are vital to the planning process. It has been first developed in Japan in 1966 by Yoji Akao (1990). It is a method for structured product planning and development that enables a development team to specify clearly the customer desires and needs (Revelle et al. 1997).

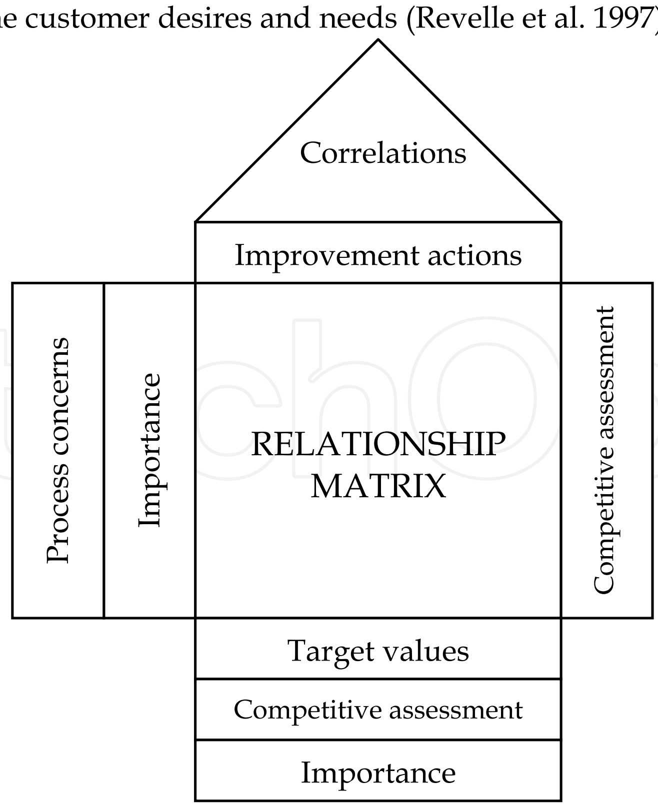


Fig. 3. House of quality for manufacturing process

The deployment of the quality functions contributes to the improvement of the process and facilitates the planning of the system design in agreement with the positioning of the company in its competing environment. The crucial importance of QFD is considered in the process of communication that it generates as well as in the decision-making. The QFD process involves constructing one or more matrices. The first one is called the House of Quality (HoQ). This consists of several sections or sub-matrices joined together in various ways, each of which containing information related to the others. There are nearly as many forms of the HoQ as there have been applications and it is this adaptability to the needs of a particular project or user group, which is one of its strengths.

4.1. Process concerns

The initial steps in forming the House of Quality include determining, clarifying, and specifying the customers' needs. These steps lay the foundation for a clearly defined venture and will prepares the enterprise to implement the maintenance excellence

4.2. Improvement actions

The next step of the QFD process is identifying what the enterprise wants (Maintenance Excellence) and what must be achieved to satisfy these wants (Maintenance Excellence Criteria). In addition, regulatory standards and requirements dictated by management must be identified. Once all requirements are identified it is important to answer what must be done to the process to fulfill the necessary requirements.

4.3. Competitive assessment

The next step in the QFD process is forming a planning matrix. The main purpose of the planning matrix is to compare how well the team met the customer requirements compared to its competitors. The planning matrix shows the weighted importance of each requirement that the team and its competitors are attempting to fulfill.

4.4. Relationship matrix

The main function of the interrelationship matrix is to establish a connection between the maintenance activity requirements and the performance measures designed to improve the process. The first step in constructing this matrix involves obtaining the opinions of the consumers as far as what they need and require from a specific process. These views are drawn from the planning matrix and placed on the left side of the interrelationship matrix.
After setting up the basic matrix, it is necessary to assign relationships between the customer requirements and the performance measures. These relationships are portrayed by symbols indicating a strong relationship, a medium relationship, or a weak relationship. The symbols in turn are assigned respective indexes such as 9-3-1, 4-2-1, or 5-3-1. When no relationship is evident between a pair, a zero value is always assigned. The interrelationship matrix should follow the Pareto Principle keeping in mind that designing to the critical 20% will satisfy 80% of the customer desires.
The QFD matrix is used to translate the priority for improvement in the specific actions.
The following relation obtains the calculation of the characteristics importance:

$$w_j = \sum_{i=1}^{I} v_{ij} \cdot u_i \tag{7}$$

where:

w_j : characteristics' weight.

v_{ij} : correlation's coefficient between the "improving ways" and the "weaknesses".

u_i : importance's weight; $u_i \in \{1,3,5,7,9\}$.

The result is then standardized to post a percentage:

$$w_j^n = 100 \frac{w_j}{\sum_{j=1}^{J} w_j} \tag{8}$$

4.5 Correlations

Performance measures in existing designs often conflict with each other. The technical correlation matrix, which is more often referred to as the "Roof", is used to aid in developing relationships between maintenance activity requirements and process requirements and identifies where these units must work together otherwise they will be in a design conflict.

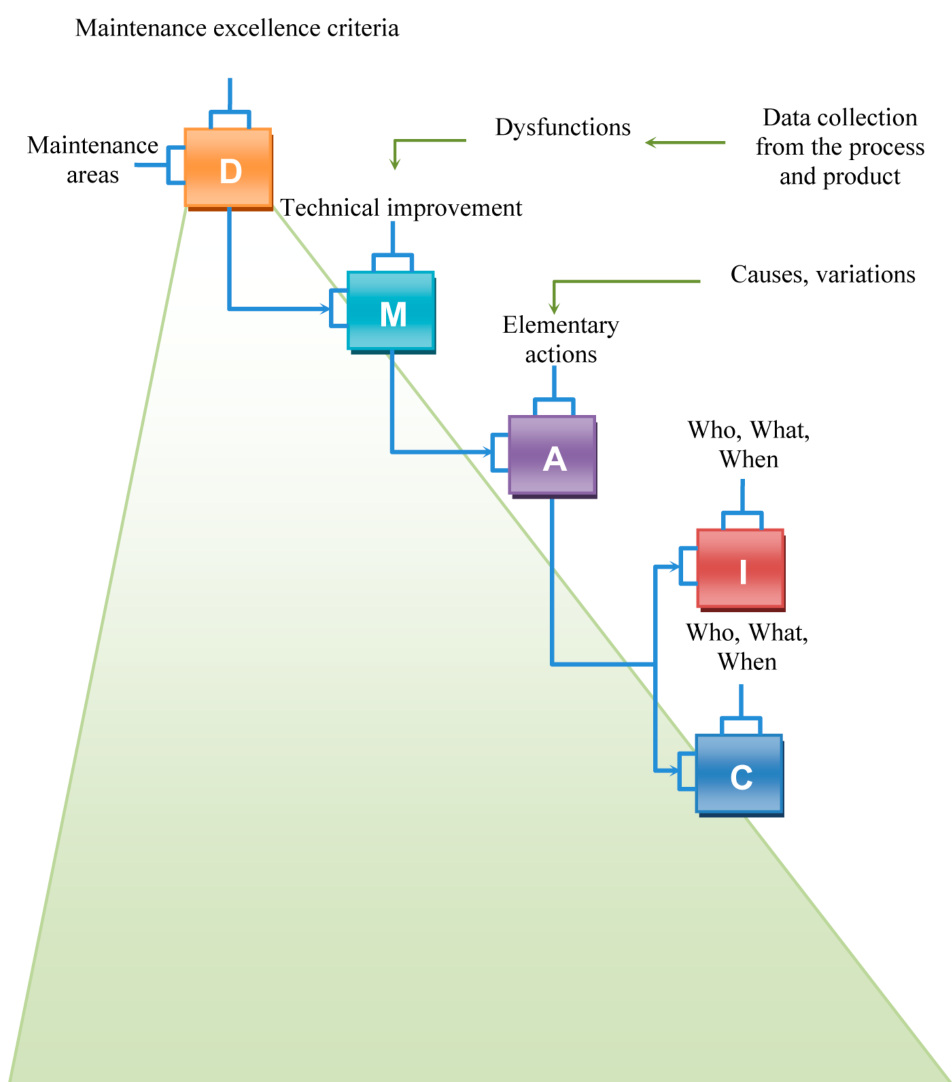
The four symbols (Strong Positive, Positive, Negative and Strong Negative) are used to represent what type of impact each requirement has on the other. They are then entered into the cells where a correlation has been identified. The objective is to highlight any requirements that might be in conflict with each other.

Any cell identified with a high correlation is a strong signal to the team, and especially to the engineers, that significant communication and coordination are a must if any changes are going to be made. If there is a negative or strongly negative impact between requirements, the design must be compromised unless the negative impact can be designed out. Some conflicts can't be resolved because they are an issue of physics. Others can be design-related, which leaves it up to the team to decide how to resolve them. Negative impacts can also represent constraints, which may be bi-directional. As a result, improving one of them may actually cause a negative impact to the other. Sometimes an identified change impairs so many others that it is just simply better to leave it alone. According to Step-By-Step QFD by John Terninko (1997), asking the following question when working with this part of the House of Quality helps to clarify the relationships among requirements: "If technical requirement X is improved, will it help or hinder technical requirement Z?"

5. The progressive improvement model

With proper interaction among ME, DMAIC and QFD (Lazreg and Gien, 2009), the manufacturing system-wide involvement and its capability of improvement and innovation can be reached. The goal is to have disciplined control of the process such as the potential defects are avoided when they do occur: the cause is immediately addressed and eradicated. Our approach is not only to correct the existing process, but also to extend it and redesign the manufacturing system.

In the process of progressive improvement, as shown in (Figure 2), the focus is trained on the identification of the Maintenance Excellence Criteria, technical improvements, elementary actions, implementation of targeted solutions and monitoring plan. In this perspective, DMAIC is applied as follows:



Maintenance areas	Maintenance Excellence Criteria	Enablers Areas	
	Data (Correlation, importance)	0	Anecdotic or without added value.
		] 0, 0.2]	Weak performance.
		] 0.2, 0.4]	Below average performance.
		] 0.4, 0.6]	Average performance.
		] 0.6, 0.8]	Very good, effective operations.
		] 0.8, 1]	World Class. Best in practice.
		Enablers Areas	
		[0, 0.25]	Disponibility of data
		] 0.25, 0.5]	Development tendency
		] 0.5, 0.75]	Internal indicators
		] 0.75,1]	Reference indicator

Fig. 4. Integrated model for progressive improvement in maintenance

5.1 Define

The first step in the DMAIC improvement cycle is the 'Define' phase, which helps the user to answer four critical questions (Pande et al. 2000) such as:

- What is the actual problem to focus on?
- What is the goal for the project?
- Who is the customer to this process and what are the effects of the problem for the customer?
- What is the investigated process?

The 'D' matrix is the initial stage of starting the improvement project. It includes the needs and concerns of a group of enterprises. They are expressed by several criteria, which describe the enterprise goals, rather than generic expressions of the future of the organization. In this stage, the needs of internal functioning are identified by all that is necessary and indispensable to reach the required performances. The identification of the MEC began with focused group of small and medium enterprises. The interviews and discussions involve their needs and expectations with priority ratings.

5.2 Measure

This phase is applied when recording the existing maintenance process and determining the processes relevant for maintenance. As a phase to examine the current state of the process, it precisely pinpoints the area causing problems; hence, using it as a basis of problem-solving. All possible and potential dysfunctions should be identified in this step. Workers-direct executives in manufacture and workers in maintenance, with their practical experience, may contribute to identify dysfunctions, as they are directly faced with concrete problems in their field of work in daily activities.

This second matrix 'M', which captures the MEC is described as 'the Voice of the Customer' in matrix rows and aligns these to the technical improvement in matrix columns. The "relationship matrix" section of the 'M' matrix measures the strength and relationships between the MEC and the technical improvement that can impede the maintenance system. These technical improvements include both quantitative (defects, failure, cost, time, etc.) and qualitative items (resistance to change, engagement of the leader, etc.). In fact, measurements of several factors, data collection and the identification of the dysfunctions which are coming from the measurement of the process, converted into quality characteristics and added to the initial technical improvement which had been already established during the definition of the expressed needs.

Moreover, the measurement in the process includes not only gathering information from the process, but also analysis of the existing information about the technical system, starting from its delivery, implementation and putting into operation, to moment of establishing a reliable way of measuring parameters and performances of the process.

5.3 Analyze

The purpose of analyzing the process of maintenance is to determine what is not good in the process, what are the causes of its inefficiency, as well as to propose the elementary actions. In fact, there are two key sources of input to be able to determine the true cause of a

problem: data analysis and process analysis. The combination of these two techniques produces the real power of our integrated model.
However, using the outputs of the 'M' matrix, which link MEC and technical improvement, the subsequent matrix 'A' deploys the elementary actions and determines the priority of each one.
The determination of the elementary actions needs a step for analyzing why, when and where the defect occurs. The objective of this step is to describe the defects statistically and to minimize various aspects of the causes in the process. When the selection process is made to detect major causes of the dysfunctions, the scientific verification process of the causes as well as gap analysis in which the discrepancy of the target value and the actual goal achieved are then conducted. Major elements to be performed in the analysis step are as follows:

- Development should be statistically and precisely defined in terms of the mean, standard deviation or regularity;
- The gap between the goal and actual state in reality should be clearly defined based on minimizing variance and moving average;
- Comprehensive list of the potential causes of the problems should be produced;
- Statistical analysis should be made to reduce the listed items for potential causes, into a few key factors;
- Basis on such analysis, objective prediction of the financial performance and re-examination should be made;
- Elementary actions should be made for the final step of improve.

5.4 Improve

It is a step to improve a few key factors confirmed in the previous analysis process and pursue a method to improve real problems to be ultimately resolved. It is also a phase to explore the solution such as how to change, fix or modify the process. If the result is unsatisfactory, additional improvement plans should be carried out.
The connection of this phase to the 'I' matrix drives the improvement process in the selection of the potential action, cost-effective solution and then workable and executable action.
Here, it is recommended that the organization makes a conscious effort to focus on a small-defined set of improvement priorities that align with the organization's broad business goals and objectives, and that should, therefore, be actually deliverable.
Once the technical plan is established, attention is then directed towards the planning of the actions, cost's re-examination, the definition of the plan timetable and the deployed resources. All these items are undertaken in the implementation matrix in order to ensure the execution of the project reorganization, which includes the assignment of the tasks. Furthermore, the development of an implementation plan is an important part of any goal-setting or problem-solving. Process, activity and task are the sub-categories used to describe in detail the content of the implemented plan. The economic report is a sub-category of the implement plan outcome referring to its quantitative economic evaluation. It can be considered to introduce the economic view in the framework of enterprise architectures.

Implementation plan is the mean by which the future is planned. It converts a goal or a solution into a step-by-step statement of 'who is to do what and when'. One benefit of this analysis would be revealing where additional resources might be needed and to point out where they can be available.

One of the most frequent reasons cited for failure of all types of change programs is the lack of communication and understanding between (a) the person who will be impacted by the changes and (b) the group involved in creating the new process and associated changes. By introducing our intermediate process, the risks of failure is reduced because there is a greater and continuing focus on the needs of the customers of the process being re-engineered.

5.5 Control

The purpose of this phase is to ensure that the voice of the maintenance function captured in earlier stages has been correctly translated into the organization. Moreover, the control phase ensures the confirmation of introduced improvements. It involves participation of all employees of the company, starting from top-managers, through teams of improvement, to the workers-operators and maintainers, who are in charge of activities according to the excellence-concept.

In this monitoring matrix (C), it is possible to deploy techniques, control methods, and monitor procedures in the realization process. Because it includes the necessary actions in each phase of the process to make sure that all the improvement actions will be under control. As far as operation is concerned, it provides the piloting means and the control methods used to control characteristics, which are likely to cause non-quality. Once established and updated, this matrix constitutes the base of the strategy of the control process and it provides the basis for the development of an effective document monitoring.

5.6 Graphical user interface

The Quality Function Deployment System (QFDS) is a Graphical User Interface (GUI) designed to manipulate QFD matrices in decision making environment. This GUI is developed using Visual Basic Language. The QFDSinstall.exe executable program can be installed to any PC with windows operating system platform. It is designed by respecting the different characteristics of the QFD process, which includes process concerns (WHATs), improvement actions (HOWs), correlations and relationship matrices, importance and competitive assessment and graphic representation.

The user interface consists of a graphical interface with pull-down menus, panels and dialog boxes, as well as a textual command line interface. The user interface is made up of four main components: a console, control panels, dialog boxes, and graphics windows.

The menu bar organizes the GUI menu hierarchy using a set of pull-down menus. A pull-down menu contains items that perform commonly executed actions. Figure 5 shows the QFDS menu bar. Menu items are arranged to correspond to the typical sequence of actions that the user perform in QFDS.

The graphical interface menu (Figure 5) shows five QFD matrices, which are created for this project. The active QFD-matrix is identified by its red color (QFD2). In this case, the user can manipulate the different characteristics of this matrix.

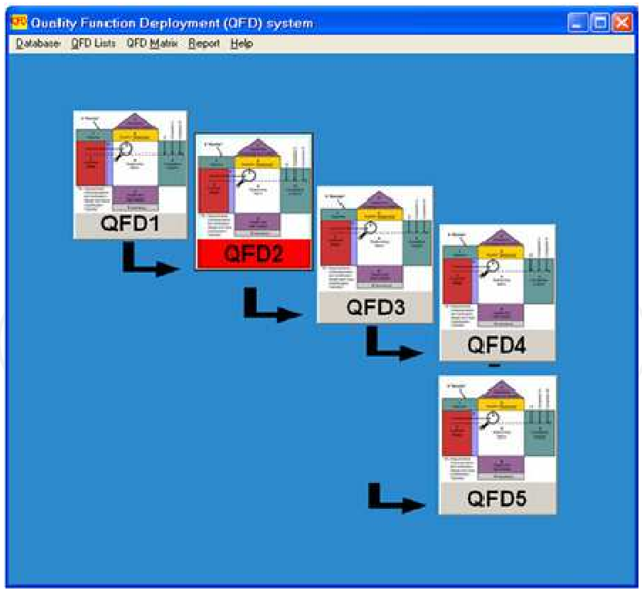
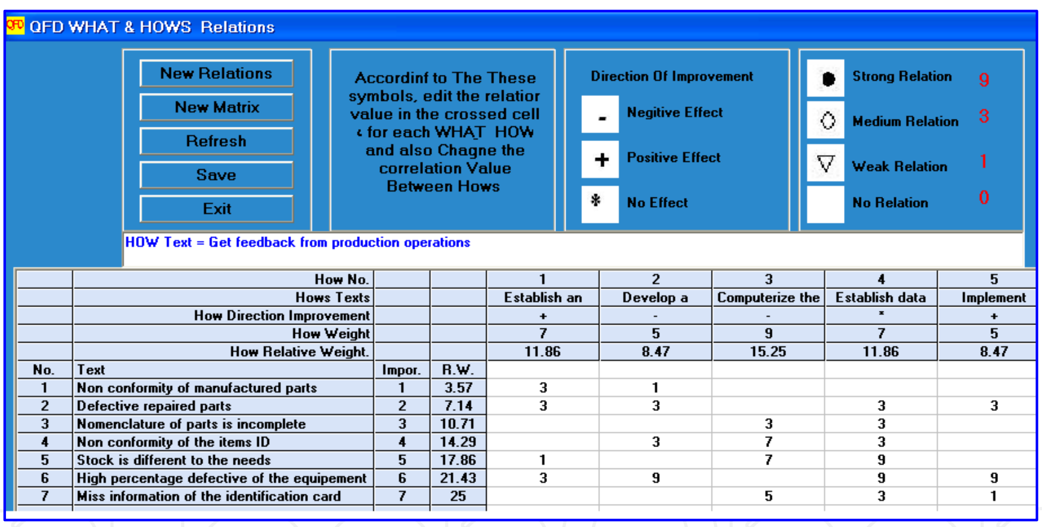


Fig. 5. DMAIC matrices

As shown in the Figure 6, the window shows how the user can edit the relation values in the crossed cells. Each value represents the correlation between 'Whats' and 'Hows'.



	How No.			1	2	3	4	5
	Hows Texts			Establish an	Develop a	Computerize the	Establish data	Implement
	How Direction Improvement			+	-	-	*	+
	How Weight			7	5	9	7	5
	How Relative Weight.			11.86	8.47	15.25	11.86	8.47
No.	Text	Impor.	R.W.					
1	Non conformity of manufactured parts	1	3.57	3	1			
2	Defective repaired parts	2	7.14	3	3		3	3
3	Nomenclature of parts is incomplete	3	10.71			3	3	
4	Non conformity of the items ID	4	14.29		3	7	3	
5	Stock is different to the needs	5	17.86	1		7	9	
6	High percentage defective of the equipement	6	21.43	3	9		9	9
7	Miss information of the identification card	7	25			5	3	1

Fig. 6. Relationship matrix

6. Case study

6.1 Presentation

The “Sotim” is a medium-sized enterprise of the production of mechanical parts. The workshop is composed of a thermal treatment unit, a manufacturing unit and a laboratory of metrology. The production operation includes: forming shop, tool room and a fully equipped product test-room. There are two assembly cells: semi-automated and manually-operated cell. An integrated computer system is used to monitor production planning and scheduling. Currently the “Sotim” employs around 43 people.

Current maintenance in this company is based on traditional practices and is reactive, i.e., breakdown. It is a practice that is inherently wasteful and ineffective with disadvantages such as: unscheduled downtime of machinery, possibility of secondary damage, no warning of failure with possible safety risks, production loss or delay, and the need for standby machinery where necessary.

6.2 Findings and limitations

- According to the results of the (D) matrix, the evaluation of the "Equipments" function, reaches 22%. Although this value represents the operation on the basis of simple procedure with functioning equipment, it does not hide in any case the technician ability and the existence of several procedures.
- The "spare parts" (A_4=0.7) function, as shown in Figure 7, is higher than the competitors ($y_{sotim}(A_4) > y_i(A_4) > y_k(A_4)$).
- The "Result" area shows certain positive tendencies and satisfactory performances.
- As well as its benefits defined so far, the QFD methodology has some limitations for practical implementations. Another point is the application process itself. The process is lengthy requiring a great deal of time, resource and effort to perform. The size of the operational and especially, technical matrices vary according to the importance of the functional activity of the enterprise.

			Example: 9 criteria from 92 items									Competitors		
		Rank	Reduce maintenance cost	Reduce the cost of the non productive maintenance	React quickly to the variations of the demand.	Improve the competencies.	Increase the multi-skill training for operators	Maximize production system effectiveness	Maximize equipment effectiveness	Improve the system quality of the maintenance.	Improve the quality of the maintenance service.	System i	System k	Sotim
	Rank		A	B	C	D	E	F	G	H	I			
Maintenance Excellence Areas	Maintenance contract	A_1	3	1				1	9		9	0.62	0.28	0.4
	Personnel	A_2				9	9	3		3	9	0.35	0.28	0.22
	Information management	A_3			1	3	9	3		9	3	0.72	0.53	0.32
	Spare parts	A_4	9	3		1	1	3	3		9	0.52	0.28	0.7
	Equipments	A_5	3		3			9	9			0.71	0.65	0.35
	Work management	A_6	3	1	9	9	3	9	5	9	9	0.45	0.72	0.18
	Preventive maintenance	A_7	9					9	9	3	3	0.48	0.48	0.25
	Organization	A_8	3	3				3	3	9	9	0.65	0.65	0.42
	Policy and strategy	A_9	3	1		1	1	3	3	9		0.4	0.15	0.28
	Dashboard	R	9	9	9	9	9	9	9	9	9	0.3	0.4	0.21

Fig. 7. Define matrix

	Add control operations	Identify every part of equipment uniquely	Standardize procedures	Standardize part.	Determine equipment performance	Restore tools in new conditions	Update the stock.	Identify needs.	Organize the purchase activity
Storeroom not secured	1							1	
Unsuitable spare parts area layout		1					1		
Difference between inventory and existing	1	1	1				9		
Inventory is not still available when needed	1		1				1		1
Miss information in index cards	1	1	1		1				
Incomplete nomenclature	1	9		9					
Incomplete catalog	1	3			3				1
Parts in stock since few years	1	1			9				1
Non functional equipment.	1		1		3	9		3	3
Relative weight	**8.19**	**13.6**	**5.94**	**7.22**	**13.3**	**13**	**10.3**	**5.62**	**17.2**
Rank	**6**	**2**	**8**	**7**	**3**	**4**	**5**	**9**	**1**

Fig. 8. Measure matrix (Qualitative data)

	Analyze equipment losses	Develop failure information	Establishing Data Acquisition Frequency	Establish a maintenance data collection system	Establish an information analysis system	Write technical Support	Get feedback from production operations	Develop engineering specifications	Calibrate the equipment
Add control operations	9	3	3	3	3	1	1		1
Identify every part of equipment uniquely	1	1	1	1	1	9	1	9	
Standardize procedures.	1	1		1	1	9	1	9	
Standardize part.	9	9	1	1	1	1	1	9	
Determine equipment performance	9	9	1	1	3	1	9	1	1
Update the stock.	9	3		3	3		9	1	1
Restore tools in new conditions	3					1			
Identify needs.	9		3	9	1		9	1	
Organize the purchase activity				1			9	3	
Relative weight	**20**	**9**	**4.8**	**11**	**6.6**	**2.1**	**31**	**4.8**	**11**
Rank	**2**	**5**	**7**	**4**	**6**	**9**	**1**	**7**	**3**

Fig. 9. Improve matrix (Qualitative data)

7. Conclusions and future development

This work focuses on developing a method of progressive improvement of the small and medium manufacturing systems. The main objectives of this chapter consist in providing a methodology and a practical support to help these systems to satisfy their needs for progress by appropriate improvement actions. The goal is the Maintenance Excellence in the enterprises, which is characterized by the satisfaction of all the external and internal users. The customer is obviously considered but the enterprise staff and workers are also included in the need definition process.

In this perspective, the "MEM-DMAIC-QFD" model is developed for determining the improvement priorities of the small and medium enterprises. This model uses QFD to apply a contingency-oriented approach to improvement priorities. It allows the maintenance activity to coordinate change in processes.

By integrating processes, methods and a technique such as Maintenance Excellence, DMAIC, Quality Function Deployment, this study provides a practical approach and useful model for manufacturing systems looking to drive balanced execution.

Moreover, the "MEM-DMAIC-QFD" model integrates the elements of management culture and quality techniques that are critical to drive performance improvement and business excellence.

This new tool solves the paradox that manufacturing systems find themselves in our present-time society able to simultaneously achieve short-term financial gains through fast business improvement projects. Moreover, it integrates the elements of management culture and quality technique that are critical to driving performance improvement and business excellence.

The subjective assignment of the relationships and weights in the matrices is another important limitation of the QFD methodology. The vagueness and the imprecision in the subjective inputs reduce the reliability of the decisions quite considerably. Therefore systems that take into account these factors should be imposed to the conventional QFD calculations. Quantitative methods such as Fuzzy sets and Grey method can be combined together with the model to improve the reliability of the decisions. In this perspective, the characteristic of the alternative with respect to the criteria can be represented in terms of a linguistic term set, and the weight of the criteria can be described by triangular fuzzy numbers, respectively.

According to the Grey and Fuzzy set theories, a closeness coefficient can be defined to determine the ranking order of all alternatives by calculating the grade of grey relation to the fuzzy positive-ideal solution and fuzzy negative-ideal solution simultaneously.

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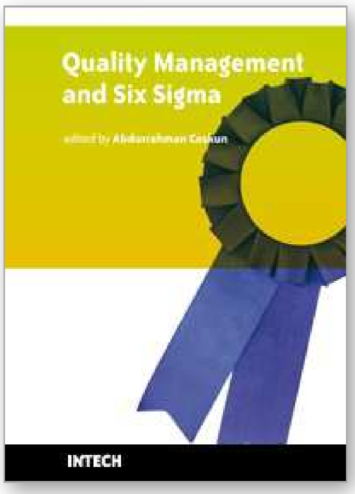

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