Application of QFD Methodology to Improve Maintenance Functions in a Manufacturing Facility

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ABSTRACT

Although QFD methodology has been traditionally used for improving product/service design, this article presents one additional important aspect of this methodology for improving the quality of the maintenance management system using a case study in a manufacturing plant. In this methodology, final product characteristics as defined by customers were mapped to lower-level operational factors of the maintenance function that were improved accordingly. Several diaper characteristics were identified and ranked as most important to consumers such as diaper absorption capacity and ease of uses; and these factors were used for subsequently improving the maintenance functions. This process of multi-stage information processing has ultimately led to major improvements in maintenance system and machine setup operations of the production line. The importance of this approach is the joint efforts of all related personnel in addressing maintenance aspects with focus on final product quality.

KEY WORDS

Quality Function Deployment, QFD, Manufacturing, Maintenance.

Introduction: QFD Process and Applications

Quality Function Deployment (QFD) began about some thirty years ago in Japan as a quality tool focused on delivering products and services that satisfy customer requirements. To effectively deliver value products and services to customers, one has to listen to the 'voice' of those customers and integrate this voice into the whole process of product or service development and delivery (Shillito, 1994). Throughout its relatively short history, QFD has gained widespread use and importance as a quality improvement tool in manufacturing and service organizations alike.

QFD is a cross-functional planning process that transforms customers' needs into detailed requirements at each stage of product development life cycle. The basic idea of this methodology is to translate the desires of customers into design or engineering specifications of a product or service and subsequently, into parts attributes, process plans and finally into product or service production requirements (Shin and Kim, 2000). Ideally, at each translation stage, QFD uses a chart or matrix that maps one set of variables to another set; for example, variables associated with customer requirements (e.g., diaper absorption capacity) can be related to design parameters (e.g., amount of super absorbing powder-sap).

Since the inception of QFD, early applications focused on manufacturing and thus the basic structure of the QFD process has been formulated in terms of the 'product' development life cycle starting with customer requirements, through product technical requirements, to production process requirements. It was until early nineties when this methodology was widely used for service organizations in distribution, education, personnel, finance, healthcare, and retail businesses (Mazur, 1993). For example, Akao, Nagai, and Maki (2001) have illustrated the use of QFD in education quality improvement, while Houston and Lawrence (2002) used the same methodology for improving the design of a quality management course. Indeed, a wide spectrum of quality and management problems can be formulated in a manner that enables using QFD structure and methodology for solving these problems. In this context, QFD can be used as general planning tool that serves business planning in manufacturing or service organizations.

In this article, we have used QFD methodology to improve the quality of the maintenance function in diaper manufacturing plant. Final product characteristics as defined by consumers were mapped to lower-level operational factors of the maintenance function; these characteristics were identified and ranked as most important to consumers such as diaper absorption capacity and ease of uses, and these factors were used for subsequently improving equipment maintenance activities and the setting up process of production line.

Production Process under Consideration

The production of diapers is a continuous high-speed process that operates at 300-500 pieces per minute, and passes through a complex set of sequential, automated, and sensitively balanced production equipment. Therefore, a baby diaper manufacturing plant was chosen to illustrate the use of QFD in improving maintenance function since in such a factory the quality of the final product depends largely on the quality of the maintenance function. The 18-step diaper production process is composed of three major stages:

1. Feeding and hammering cellulose pulp
2. Diaper forming
3. Diaper folding, stacking and packaging

During first stage, a series of operations takes place including feeding initially wrapped cellulose pulp on reels to the start of production line, hammering pulp to change it to fluff, pouring super absorption powder (sap) into fluff material, and gluing powdered fluff with preheated poly film. The second stage consists of gluing frontal tapes, application of non-woven film, fluff compression, attaching of bi-adhesive tape tabs, diaper shaping and longitudinal forming, and final diaper cut. The last stage takes individual diapers into a folding unit, stacker, and finally packaging unit.

The motion of the material is controlled by a conveyor belt and transfer drums, combined by a large number of photovoltaic cells and mechanical switches that enable machine to perform quality checks and provide alarm signals to production line operators. In the production line under consideration, about 10 main units are involved in performing the above 18 steps, among which are pulp feeding unit, ploy film unit, elastic thread application and feeding, non-woven unit, frontal tape, and others. Diaper quality characteristics such as diaper dimensions, amount of sap powder, or even orientation of diaper frontal tape are all determined by how well the production line components are initially set up, aligned and synchronized. As such, the effective and smooth operation of the production line is significantly determined by the quality of the maintenance activities.

Research Methodology: a 3-Stage QFD Process

Traditionally, the QFD process has 4 stages of information mapping and processing (Shillito, 1994). The first stage, known as product planning, relates customer requirements to product technical requirements, while the second, known as part planning, relates product technical requirements to product part characteristics. The third stage, process planning, maps part characteristics to manufacturing processes, and finally, the fourth mapping, known as production operation planning, takes place between manufacturing processes and operations control. Depending on the objectives of the study and required level of details, number of information processing stages can be changed.

The goal of this study is to use QFD methodology to examine the impact of maintenance function on final product quality and identify critical areas for improving maintenance activity. In this effort, a 3-

stage information transformation methodology has been implemented, and these stages are shown schematically in Figure 1 and explained as follows.

1. Examining customers' quality requirements and associated product technical requirements (PTRs), and the output of this stage consists of the House of Quality (HOQ).
2. Mapping product technical requirements to manufacturing processes and the output of this stage is a defined set of critical manufacturing processes that affect product quality.
3. Mapping manufacturing processes to maintenance activities and the output of this stage is a defined set of most important maintenance activities that must be carefully established and implemented to assure smooth and effective operations of manufacturing processes.

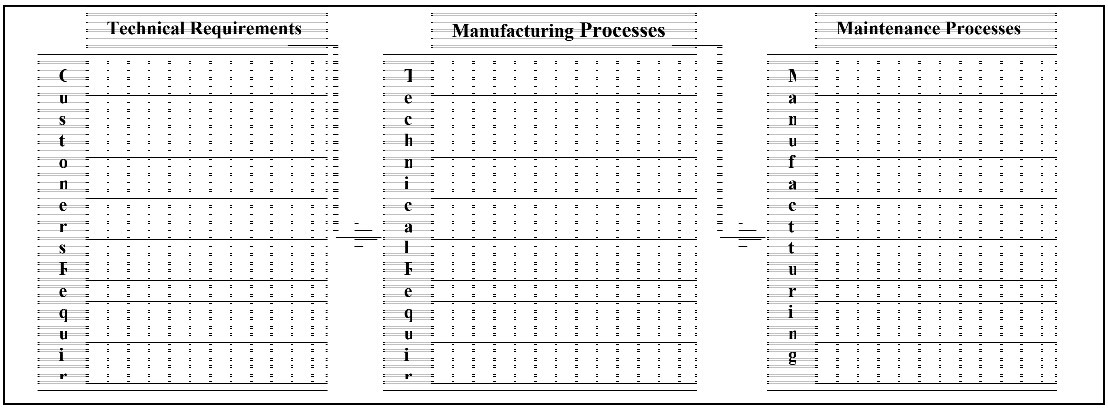

Figure 1. QFD Methodology Relating Customers' Requirements to Maintenance Function

Each of the above stages requires certain variables and data to be compiled using market studies and/or experience of the QFD team. For example, construction of the House of Quality (i.e., stage 1) requires identification of customers' requirements (i.e., voice of customers- VOC), product technical requirements (PTRs), and market competition data. Stage 2 requires knowledge of manufacturing processes that directly or indirectly affect product technical requirements, while knowledge of maintenance processes and their impact on production operations are necessary for stage 3 analyses.

Constructing HOQ: Basic Data Collection and Verification

QFD is teamwork methodology that combines key functions in the organization including quality, design, manufacturing, and sales and marketing. Each of these parties has a key role to play in implementing a QFD project, and since this QFD study was implemented at a manufacturing factory, a team was established of the department heads of production, quality, and sales and marketing departments. In this 3-month study, QFD team held many meetings to plan market studies for the product under consideration, called "*Lucky Baby*", verify and analyze data using QFD approach, and make final recommendations on improving maintenance functions. Teamwork techniques such as brainstorming and voting/selection were used as well as various data analysis tools including affinity diagrams, tree diagrams, and cause-and-effect diagrams.

A market study targeting households and mothers aimed at identifying diaper critical diaper requirements and produced a list of important factors as given in Table 1.

Table 1. Most Critical Diaper Quality Requirements as given by Customers - VOC

#	Customer Requirement	Relative Weight
1	Diaper should prevent baby sensitive from developing red skin or allergic effects	81%
3	Diaper must have high absorption capacity	76%
3	Long time for diaper change	68%
4	Comfortable reusable taping panel	49%
5	Shape of diaper should be attractive	35%

Based on the response of customers to the most critical aspects of a baby diaper, QFD team held meetings to determine the corresponding technical requirements relating to design factors of the diaper that would impact diaper performance. The results of extensive discussions and analysis produced the following affinity diagram relating customers' requirements and product technical requirements (Figure 2).

Comfortable Taping Panel	Long Period Use
• Type of used rubber • The gauze • Diaper dimensions • Adhesive materials	• Quantity and distribution of sap powder • sap-pulp ratio
Shape of Diaper	**Prevent Allergy**
• Diaper dimensions	• Type of used rubber • The gauze
Absorption Capacity	
• Quantity and distribution of sap powder • Sap-pulp ratio	

Figure 2. Affinity Diagram of Customers' requirements and Product Technical Requirements

A second more extensive market competition study was conducted to identify existing competitors, market shares, pros and cons of each competitor, and expected sales improvements if additional product design and developments were introduced to the Lucky Baby product. The results of this study are summarized in the HOQ matrix in Figure 3. For this study, the correlations among product technical requirements were not estimated as they were deemed to be unimportant.

It should be noted that the construction of the HOQ requires that QFD team define a rating system for evaluating the strength of relationships between VOC and PTRs and for representing market competition data. In this study, a (0-10) point rating system was used and computations of the **scores** and **%scores** of VOC and PTRs were made according to formulae presented by Shillito (Shillito, 1994). Values representing strength of relationships among variables have been determined based on results of market studies and expertise of QFD team. From the HOQ above, it becomes obvious that most important product technical requirements were in this order: amount of pulp (gm), amount of super absorption powder (gm), amount of gauze (gm/m^2), rubber (gm), diaper dimension (mm), finally type of adhesive materials and gluing (mm). These product characteristics and related manufacturing processes were used as a basis for constructing process matrix.

Customer Requirements (VOC)		**Importance**	**Product Technical Requirements (PTRs)**							Lucky baby Today	Huggies	Pampers	Lucky baby in future	Improvement ration	Sale points	**Score**	**Score %**
			SAP	Pulp	Adhesive	Gauze	Rubber	Dim.									
1	Absorption	9	9	8	0	6	0	4		3.5	4.5	4.3	4.8	1.37	1.1	13.56	26.67
2	Comfort in use & taping	8	2	8	8	8	9	8		3.7	4.3	3.9	4.5	1.21	1.0	09.68	19.10
3	Prevent Allergy	8	6	6	0	8	9	4		3.5	4.5	4.3	4.5	1.28	1.0	10.24	20.20
4	Long Period of use	6	9	7	6	2	2	4		2.1	3.4	2.9	3.5	1.66	1.1	10.95	21.60
5	Attractive shape	5	0	0	6	6	8	8		2.8	3.1	3.0	3.5	1.25	1.0	06.25	12.34
	Score		5.94	6.39	3.56	5.92	4.96	4.25		31.02						50.68	100 %
	Score %		**19.14**	**20.61**	**11.47**	**19.08**	**15.98**	**13.70**		100%							
	Measurement Unit		gm	gm	mm	gm/m²	gm	mm									

Figure 3. House of Quality for the Diaper Manufacturing Example

Construction of Process Matrix

Based on the results of the analysis presented in the HOQ, QFD team started to identify relevant factors that affect product requirements and based on lengthy discussions among production, quality, and maintenance staff at the factory, a general consensus was reached on a set of such factors. As said earlier, in this study, these factors represent processes that have significant effects on the product technical requirements. Cause-and-effect diagrams were used for this purpose and a sample of this analysis is shown in Figure 4.

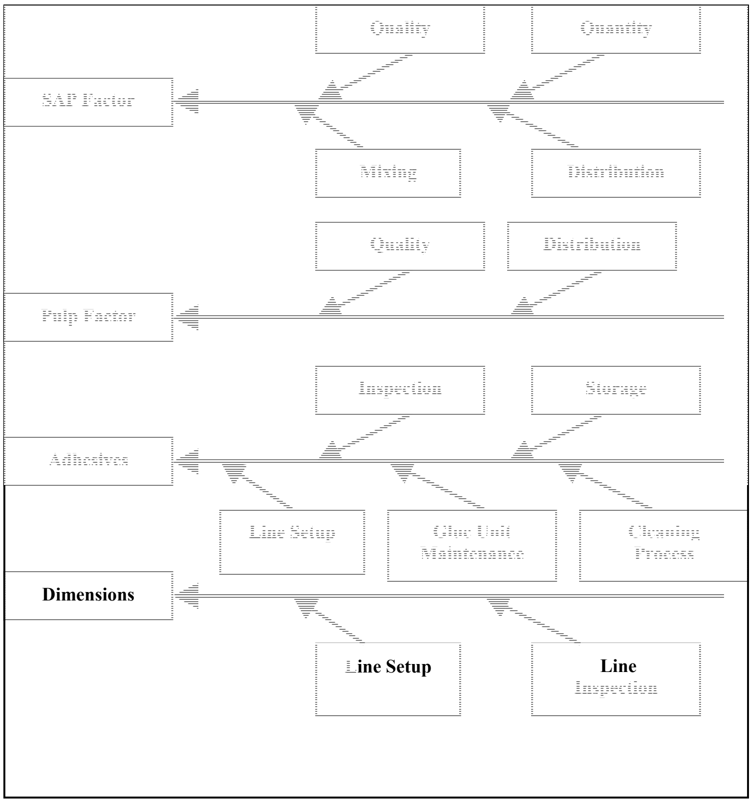

Figure 4. Cause-and-Effect Diagram of PTRs and Production Processes

As seen from Figure 4, important processes impacting PTRs can be narrowed into few factors. These were used to construct the process matrix whose output will be most critical processes that impact product quality. One can observe from the analysis that processes involved are not only manufacturing operations as initially stipulated in the QFD approach, but also other auxiliary production processes such as maintenance, line set up, storage, or materials inspection.

Following same rating system as used above for constructing HOQ, the matrix representing PTRs-Process mapping is given below in Figure 5 where six PTRs are mapped to seven processes.

Product Technical Requirements	**P R O C E S S E S**						
	SAP Distribution	Pulp Distribution	Cleaning	Equipment Inspection	Line setup	Storage of Glue	Maintenance of Glue Nozzle
Pulp Factor	5	9	6	6	8	2	0
SAP Factor	9	5	6	8	8	2	0
Gauze	4	4	6	8	7	2	2
Rubber	0	0	8	8	7	0	1
Dimension	0	0	3	9	9	0	2
Adhesive	0	0	7	9	7	9	9
Score	18	18	36	48	46	15	14
% Score	**9.2**	**9.2**	**18.46**	**26.61**	**23.58**	**7.7**	**7.7**

Figure 5. Process Matrix: Mapping of PTRs to Processes

As in the HOQ, it should be noted that numbers in the shaded area above representing the strength of the relationships among variables are judgmental and reached by consensus among QFD team particularly the technical staff of the production, quality, and maintenance operations. Again % scores represent the relative importance of processes, and it is clear that processes vary in their impact on product final quality. Top 3 critical processes are in this order: equipment inspection (26.61), line setup process (23.58), and cleaning operations (18.46). Using these 3 most important processes, the next and final QFD process in this study will examine the relationships among maintenance activities and these technical processes.

Construction of Maintenance Matrix

Having identified and defined a clear set of production process as most important to the production of high quality products, the next step in this study is to investigate relationships among these processes and maintenance activities of production equipment and tools. This step is aimed at recognizing critical maintenance activities, whether analysis and planning, implementation, resources, or human training, so that management will keep focus on these aspects of the maintenance process to ensure smooth and effective production line operations.

QFD team followed a similar analysis approach as outlined above for identifying relationships between most significant processes and related technical activities, mainly maintenance activities. The following table defines the factors that affect each of these processes.

Table 2. Factors Affecting Processes

#	**Significant Process**	**Related factors**
1	Equipment Inspection	Frequency
		Operator training
		Sensors' readiness
		Production schedules
		Inspection tools
		Inspection reports
2	Equipment Cleaning	Type of cleaning solvent
		Operator training
		Frequency
		Availability of materials
		Cleaning reports
3	Line Setup	Sensors' operation
		Production schedules
		Operator training

The QFD matrix in Figure 6 summarizes the relationship between above variables where the (0-10) scale system was used again for evaluating the strength of these relations. Values in given below have been reached as a result of mutual discussions among project team.

#	**Frequency**	**Training**	**Sensors' Readiness**	**Production Schedules**	**Tools**	**Reports**	**Cleaning Solvent**	**Material Availability**
Inspection	9	9	7	5	7	9	3	8
Cleaning	9	8	5	5	5	8	9	9
Line Setup	6	9	9	5	8	7	2	6
Scores	**24**	**26**	**21**	**15**	**20**	**24**	**14**	**23**
%Score	**14.4**	**15.6**	**12.5**	**8.9**	**11.8**	**14.4**	**8.7**	**13.7**

Figure 6. Maintenance Process QFD Matrix

Proposed Improvements in the Maintenance System

The analysis above indicates important facts about the maintenance process. First, as a result of collective discussions among key staff in the factory, all important factors relating to the maintenance process are revealed. The calculations in the QFD matrix gives priority indicators as to what factors should receive most attention in re-engineering the maintenance process. From Figure 6, it can be concluded that these factors need careful re-consideration: training of maintenance technicians, maintenance frequency, inspection reports, availability of cleaning materials and spare parts, readiness of sensors and actuating switches, and finally production schedules and quality of cleaning solvents.

Based on the above analysis, a comprehensive improvement plan has been proposed for the maintenance function. Prioritized set of factors above represent the basic components of this plan, in particular, qualifications and training of maintenance staff, maintenance reporting system, establishment of a preventive (inspection) system, availability of spare parts, and integrating the maintenance process in more comprehensive production planning process. An improvement plan combining all such factors was presented to company management with a time schedule for introducing improvement programs. For example, a training schedule was prepared for improving skills of technicians, an integrated maintenance documentation system was established, a modified material purchasing policy was adopted for buying maintenance materials and spare parts, and a strict preventive maintenance schedule was prepared and approved.

Conclusions

This article has presented a methodology for linking final product quality to the quality of maintenance function in a manufacturing plant. The importance of this process is the jointly performed analysis and discussion of relevant data by key personnel in the factory including, design, quality, production, sales and marketing, and maintenance. In a 'traditional' approach to maintenance analysis, it is not common that one would fail to recognize the above factors; however, this new methodology gives an opportunity to address all related factors, their impact on quality, and prioritize these factors so that further investments would be wisely allocated.

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