METHODOLOGY AND THEORY

Integrating TPM and QFD for improving quality in maintenance engineering

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Abstract

Purpose – To provide maintenance engineering community with a model named "Maintenance quality function deployment" (MQFD) for nourishing the synergy of quality function deployment (QFD) and total productive maintenance (TPM) and enhancing maintenance quality of products and equipment.

Design/methodology/approach – The principles of QFD and TPM were studied. MQFD model was designed by coupling these two principles. The practical implementation feasibility of MQFD model was checked in an automobile service station.

Findings – Both QFD and TPM are popular approaches and several benefits of implementing them have been reported worldwide. Yet the world has not nourished the synergic power of integrating them. The MQFD implementation study reported in this paper has revealed its practical validity.

Research limitations/implications – Since MQFD requires strategic decision making, the management commitment and support are required to test implement it. Since the case study was conducted in a public sector service station, this could not be achieved due to the requirement of following complex administrative procedures. However, the feasibility of obtaining customer voices

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from the practising community and translating them into technical languages has revealed the possibility of implementing MQFD in real time situations.

Originality/value – Both literature and manufacturing arenas were surveyed and found out that no model linking QFD and TPM has so far been brought out by theorists and practitioners. Hence the contribution of MQFD model is original. Since there are researches establishing the power of QFD and TPM, the essence of integrating them for attaining world class maintenance quality is of high value.

Keywords Productive maintenance, Quality function deployment, House of quality, Surveys

Paper type Case study

Introduction

During recent years, organisations have been adopting strategies for enhancing the maintenance quality of products and processes as a means to excel in today's competitive world. One of the current strategies being adopted in this direction by modern organisations is total productive maintenance (TPM) (Ahmed *et al.*, 2005; Wang and Hwang, 2005) In essence, TPM couples the principles of maintenance engineering and total quality management (TQM) (Seth and Tripathi, 2005). While few TQM strategies have been adopted, the strategy of infusing customer voices is yet to find its authentic place in TPM field. For example, customers voice the maintenance quality of products by citing the quality of service levels that they receive, against the preferred levels (Tan and Pawitra, 2001). There is no technique or tool available in TPM to transfer this kind of customer voice into practical arena. Whereas in TQM literature, a considerable portion of deliberations is devoted towards the use of the technique called "quality function deployment" (QFD), for converting the voice of customers into technical requirements.(Fung *et al.*, 1999) Majority of the researchers have reported the benefits achieved by implementing QFD (Zairi and Youssef, 1998, Kathawala and Motwani, 1994; Olhanger and West, 2002). In this context, we developed the presumption that if QFD is adopted in TPM projects through a suitable mechanism, then it will be a highly beneficial proposition for achieving higher degree of maintenance quality. Hence in this paper a model is proposed, which is named "maintenance quality function deployment" (MQFD). We carried out two phases of activities before designing MQFD model. First we reviewed literature and found out that no activities have so far been reported on integrating QFD in TPM and vice versa. During the second phase we surveyed six TPM implementing companies. The survey results indicated that no effort on integrating QFD in TPM has been exerted in practical arena. After completing these two phases of activities, the MQFD model was designed. In order to examine the working of MQFD in real time situation, its implementation study was conducted in an Indian state government run public sector automobile service station. The details of this work are presented in this paper.

Use of QFD for TPM

Both QFD and TPM have widely been in existence during last three decades (Akao and Mazur, 2003; Nakajima, 1993; Chan *et al.*, 2005). Though their objectives are about the quality improvement aspects, their perceptions and orientations are focused on attaining different objectives. In order to enable the nourishment of their synergic benefits, it becomes necessary to examine the use of QFD for TPM. This aspect is depicted in Figure 1. As hinted, the objectives of QFD are largely on meeting the external customers' requirements through the involvement of management staff,

Objectives of QFD 1. To translate customer's vague languages into technically understandable languages 2. To enable the percolation of customer's voice into practical arena 3. To facilitate the customer's voice to obtain exactly what he/she wants (Sahney *et. al.* 2004)		Objectives of TPM 1. To achieve zero break downs 2. To achieve zero defects 3. To achieve improved throughputs		Synergic objectives of QFD and TPM To gather both internal and external customer's perceptions in achieving zero break downs, zero defects and improved throughout and translate them into practically implementable and viable propositions
Benefits of QFD 1. Development of team work and participation culture 2. Systematic development of documentation connecting all functional requirements 3. Reduced field problems 4. Lesser design changes 5. Identification of strengths and weaknesses of products with reference to competitors products (Lokamy and Khurana, 1995)	+	Benefits of TPM 1. Cultivating sense of ownership of equipment among the operators 2. Development of cross functional teams to improve individual employee and employer performance 3. Increase the life of equipment and plant 4. Identification of reasons for equipment failures 5. Increase in motivation level of employees (Eti. *et. al.* 2004)	=	Synergic Benefits of QFD for TPM Development of teams consisting of not only operators but also managers who are concerned with equipment effectiveness for providing tangible and intangible gains that would be received by both internal and external customers

Figure 1.
Use of QFD for TPM

whereas the objectives of TPM are mainly concentrated on the enhancement of operators' capabilities towards enhancing maintenance quality of equipment. These differing objectives will lead to the division between management staff and the operators. If QFD is properly integrated with TPM programme, then those differing objectives can be focused towards the unified direction of achieving continuous maintenance quality improvement. However this would be a challenging task. Because, QFD professionals have not so far applied it for improving equipment's maintenance quality. Likewise TPM professionals have not been orienting towards continuous maintenance quality improvement of products produced by the organizations. Hence the task of integrating QFD and TPM has to be carried out with precautions because of their inherent divergent objectives.

QFD in TPM and vice versa: a literature perspective

On realizing that QFD adoption in TPM projects would be a useful contribution to TPM professionals, we developed interest to locate any work that reports the adoption of QFD in TPM projects and vice versa. In this regard, it was very encouraging to see an article by Chan and Wu (2002). They have reviewed as many as 650 publications, which are considered to be relatively an exhaustive literature on QFD. They have dealt QFD right from its birth to its dissemination to various countries and fields. They have listed the popular application fields of QFD, which include product development, quality management and customer need analysis. They have also identified the industrial sectors in which QFD is applied. Some of them are transportation, communication, software systems and manufacturing. In addition to that, they have listed articles, which report the linking of QFD with simultaneous engineering, knowledge intensive engineering, quality engineering, rehabilitation engineering, requirement engineering, quality engineering and so on. However this list does not include TPM. On the whole, the review of this paper clearly indicated the absence of any work linking TPM with QFD.

In order to further confirm the absence of QFD application in TPM field, some more papers were reviewed. Some of those reviews are briefly presented here. Terziovski and Sohal (2000) have collected responses from approximately 400 managers. They have integrated the use of seven new quality tools. Failure mode and effect analysis, QFD, creativity tools, standardization tools and "5S" for achieving continuous improvement. They have cited that some companies use TPM as a tool for *kaizen*. However they have not indicated any work involving the application of QFD in TPM and vice versa. Rho *et al.* (2001) concentrated on various studies designed to investigate the relationship between manufacturing strategies, practices, and performance. They have compared the results from three different nations, Korea, USA and Japan. They have included TPM and QFD in their studies but have not attempted to integrate them. Negri and Galli (1997) have worked on the quality improvement strategies in Italy and have cited that TPM influences on process control on preventive basis and it minimizes down time. They have identified QFD as one of the most effective and reliable approach to technological development and relevant processes. However they have not mingled QFD and TPM with each other in their studies.

Voss and Blackmon (1998) studied the differences in manufacturing strategies between Japanese and Western manufacturing companies. Cultural differences caused difference in attitude towards duration of implementation, which lead to the adoption of long term and short term strategies. They have analyzed the data from 600 companies in 20 countries. They have mentioned that Japanese considered TPM as one of the long-term strategies. They have reported a higher level of adoption of QFD than TPM in Japan. They have also reported higher payoff of TPM than QFD, whereas this trend is reversed in western countries. However the difference in these quantified parameters is very less and hence, we inferred that TPM and QFD are dominating in both Western and Japanese companies. However, this study reveals no integration between TPM and QFD principles.

After realizing the absence of any article regarding the integration of QFD and TPM, we developed curiosity to check whether any attempts have been made to link any other manufacturing strategies with them. It was quiet surprising to see few articles, authored my McKone *et al.* (1999, 2001) Cua *et al.* (2001) which have emerged in this direction. These articles indicate the feasibility of linking both TPM and QFD with other similar approaches with different combination. Hence it is inferred that the marriage of QFD and TPM will also be feasible proposition.

QFD in TPM and vice versa: a perspective in the practical arena

While the literature review hinted the absence of any work on integrating QFD in TPM programs, we developed interest to assess the status in practical arena. For this purpose, we designed a feed back questionnaire. This questionnaire consisted of two components. The first component consisted of ten questions and aimed to assess the level of TPM implementation in the responding company. The second component contained four questions and aimed at checking the implementation status of QFD in the responding company. With this questionnaire, five TPM implementing companies located at Coimbatore City of India were visited personally by the first author and the responses were collected from the competent authorities. Besides the questionnaire was sent through e-mail to 53 TPM implementing companies located in India. However the filled-in questionnaire was received from only one company. The responses gathered through these filled-in questionnaires are analyzed in this section.

Since some companies are reluctant to reveal their identities, hereafter the companies will be referred to as Company 1, Company 2 and so on. The questions in the first component of the questionnaire aimed to estimate the level of implementing eight pillars of TPM. It was observed that no company has fully constructed TPM pillars. In company 2 the fifth TPM pillar (titled as office TPM) has not been implemented at all. Also the overall percentage level of constructing TPM pillars in the companies range from 32-61 percent. These levels affirm that these companies can be considered as TPM implementing companies. In order to determine the feasibility of merging TPM in QFD, the status of utilizing internal and external customers' concept was examined (Kruger, 2001). Since QFD deals with transferring customer's vague language into technical language, the proportion of utilizing of internal and external customers' concept while implementing the TPM programmes was examined using a question. Except in the case of company 6, the level of utilizing internal and external customers' concept is either nil or very less. The overall proportion of the six TPM companies implementing internal and external customers' concept is very less (40 percent). Another question aimed to determine whether the company ever implemented QFD. Barring companies 2 and 4, other companies have never implemented QFD. Hence the QFD implementation status was gathered only from companies 2 and 4 using a Likert's scale of range 0-10. Further responses to a question indicated that the implementation of QFD in these companies was confined within top and middle level management personnel. It was observed, company 2 has reaped very little benefits while company 4 has gained benefits in all aspects by implementing QFD. This observation indicates that, the benefits gained by implementing QFD are proportional to level of its implementation. On the whole, the questionnaire supported surveys in the above six TPM implementing companies led to the drawing of the following inferences:

- Though some authors have reported that TPM is one of the world class manufacturing strategies (McKone *et al.*, 2001; Yamashina, 2000), its level of implementation with reference to the eight pillars is not very appreciable.
- There exists every possibility that a company may implement TPM without installing one or more of the TPM pillars.
- TPM implementing companies possess no or very little knowledge about QFD since TPM does not stipulate the incorporation of internal and external customers' concept.

There is no sign of the six TPM implementing companies applying QFD in their TPM projects. On the whole, the results of literature and surveys did not reveal any difference. In other words, both literature and practical surveys confirmed that no authentic model linking TPM and QFD is adopted today in either research or practice.

MQFD model

While ascertaining the absence of any model linking TPM and QFD in both literature and practical arenas, two methodologies of linking these two principles were examined. One methodology is that, QFD can be introduced in TPM principles. Other methodology is that, TPM can be introduced in QFD projects. In both methodologies, there is every likely chance that these two principles do not get linked so that the synergic benefits are not gained. Hence we decided to design MQFD model exclusively for linking these two principles. The conceptual features of MQFD model are shown in Figure 2. As shown, the performance of a company will be heard through the voice of customers. Those voices of customers are used to develop the house of quality (Chein and Su, 2003). This process has to be accomplished by QFD team. The outputs of QFD, which are in the form of technical languages (Rahim and Beksh, 2003), are submitted to the top management for making strategic decisions. This step is necessitated because researchers have established the need of applying strategic approach in both QFD (Lu and Kuei, 1998) and TPM (Murthy *et al.*, 2002; Hunt and Xavier, 2003) projects for ensuring their success. The technical languages which are concerned with enhancing maintenance quality are strategically directed by the top management for progressing through the eight TPM pillars. The TPM characteristics developed through the development of eight pillars are fed into the production system. Their implementation shall be focussed on increasing the values of the maintenance quality parameters, namely overall equipment efficiency (OEE), mean time between failures (MTBF), mean time to repair (MTTR), performance quality, availability and mean down time (MDT). The outputs from the production system are required to be reflected in the form of improved maintenance quality, increased profit, upgraded core competence, and enhanced goodwill. All the quantified values of outputs are used for developing another house of quality and comparing with the set targets. Now the next cycle begins. Thus implementation of MQFD model is a never-ending continuous improvement process. A unique feature of MQFD model is that it does not envisage changing or dismantling the existing process of developing house of quality and TPM projects which may be under practice in the company concerned. Thus MQFD model enables the tactical marriage of QFD and TPM.

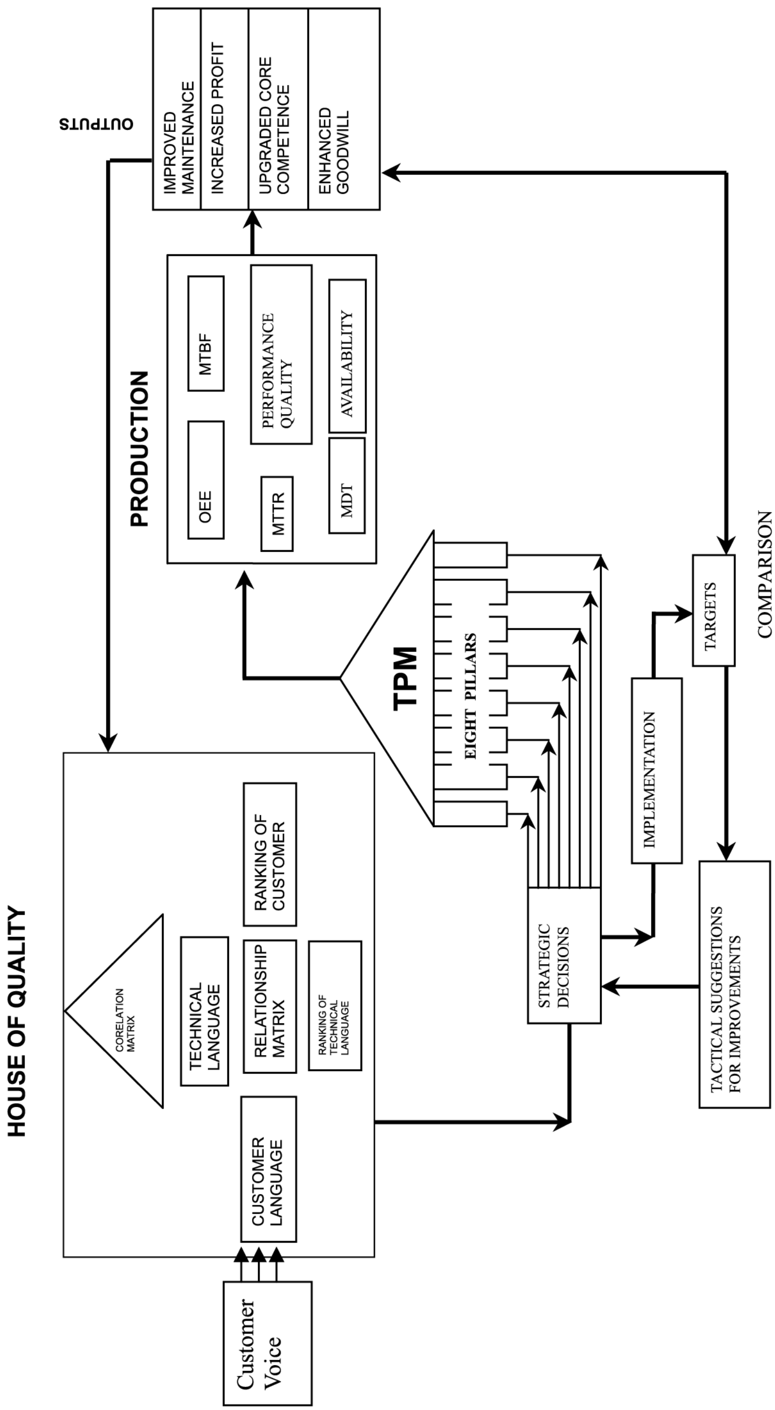


Figure 2.
MQFD model

Case study

In order to examine the implementation aspects of MQFD, a case study was carried out in a maintenance intensive automobile service station. This service station is located at Coimbatore city of India. This service station is run by the Tamil Nadu state Government of India. This service station is required to cater to the maintenance requirements of Tamil Nadu state Government's vehicles. This service station was chosen for the study because of the intense maintenance engineering activities being carried out in it. To begin with, the customer reaction was obtained using a questionnaire. The drivers of the vehicles are the customers of this service station. By making use of the long experience of the fifth author, the list containing the maintenance quality aspects was prepared. The drivers were asked to mark their reactions against those aspects. In total, the reactions from 14 drivers were collected pertaining to 20 maintenance quality aspects. The data collected through this questionnaire based survey is tabulated in Table I. As an example, the details of the data presented against serial number 1 in Table I are illustrated here. This question aimed to gather the reaction of each driver about the condition of the driver's seat of the vehicle. Out of the 14 drivers, three of them have mentioned "excellent", while five and six of them have mentioned that it is "good" and "average" respectively. None of them have felt that the driver's seat of the vehicle that they drive is in bad condition. The selection of maintenance quality aspect was prioritised on the basis of drivers' reactions in the order ranging from "Bad" to "Excellent". That is, the maintenance quality aspects in which "Bad" reactions dominate are given the highest priority in

Serial number	Customers' voice	Number of drivers' responses: Excellent priority	Good priority	Average priority	Bad priority	Priority scores
1	Condition of driver's seat	3	5	6	–	31
2	Condition of rear-view mirror	1	11	1	1	30
3	Condition of headlights	1	6	4	3	37
4	Engine condition	4	6	3	1	31
5	Condition of gearbox	2	7	4	1	32
6	Condition of transmission	1	8	4	1	34
7	Condition of suspension/springs	1	6	6	1	36
8	Condition of tyres	2	7	3	2	33
9	Condition of steering	1	6	5	2	36
10	Condition of brakes	–	11	3	–	34
11	Condition of clutch	–	12	2	–	33
12	Ride comfort	–	6	7	1	37
13	Handling characteristics	1	11	1	1	30
14	Oil leaks, if any	–	10	4	–	32
15	Fuel efficiency	–	9	4	1	34
16	Periodic maintenance	1	11	2	–	29
17	Response from maintenance department about problems	1	8	5	–	32
18	Control of repeated breakdowns	1	9	4	–	31
19	Consideration of drivers' suggestions by maintenance personnel	–	9	4	1	34
20	Skill of maintenance workers	1	9	3	1	32

Table I. Data on customers' voice

choosing for subsequent study. It is gradually decreased from average to excellent reactions. The priorities were quantified by assigning weightages 1, 2, 3, and 4 for the reactions "Excellent", "Good", "Average" and "Bad" respectively. The priority thus computed has been entered in the last column of Table I. As a sample the computation of the expected value against the condition of the driver's seat is presented below.

$$\text{Number of "Excellent" reactions} \times 1 + \text{Number of "Good" reactions} \times 2$$
$$+ \text{Number of "Average" reactions} \times 3 + \text{Number of "Bad" reactions} \times 4$$
$$= (3 \times 1 + 5 \times 2 + 6 \times 3 + 3 \times 0) = 31.$$

As shown in the last column of Table I, the "ride comfort" and "condition of the head light" shall be the highest priorities for choosing subsequent study since their score is 37. This score is the highest among all. These details were input into "House of quality"(Besterfield *et al.*, 2004) shown in Figure 3.

After this, the technical languages numbering 32 was prepared by the fifth author. The driver's reactions (which are referred to customer voices in QFD terminology) and the technical languages were entered in rows and columns of the correlation matrix. The correlation between the customers' voice and technical languages were entered using three symbols, which are shown below:

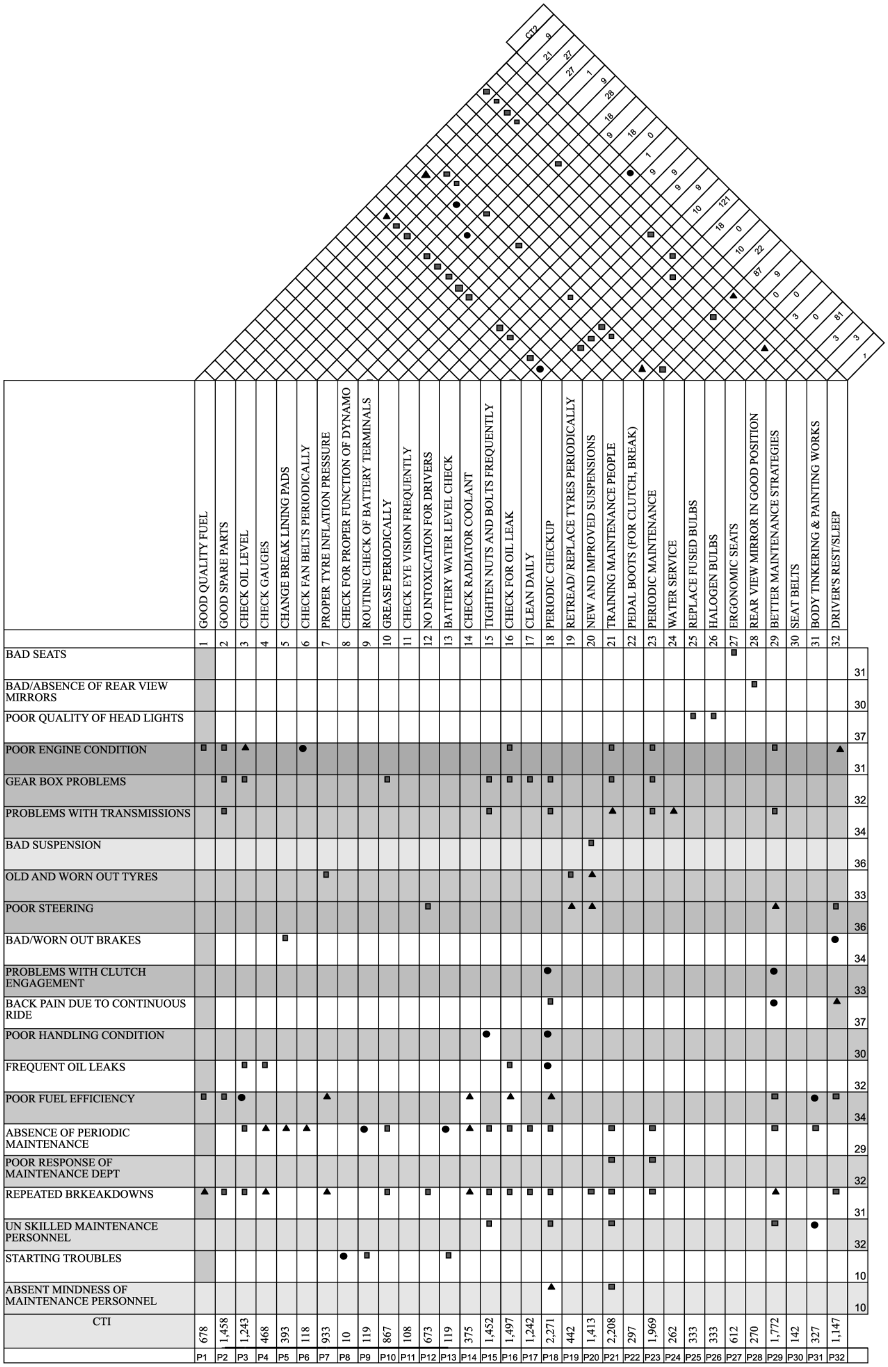
(1) Strong relationship = ■
(2) Medium relationship = Δ
(3) Week relationship = •

In case of no relationship, the corresponding cell is left blank. These data were entered into the HoQ matrix shown in Figure 3. Followed by that the correlation matrix was developed using the same symbols used for constructing relationship matrix to bring out the correlation among technical languages. In order to quantify the relationships and correlate using numerical values, the pattern followed by Lu and Kuei (1999) for quantifying the relationships was used. Accordingly, the values 9, 3 and 1 were assigned to strong relationship/ correlation, medium relationship/ correlation, and week relationship/ correlation respectively. No values were assigned against blank cells. These values were used to compute customer-technical interactive scores and weighted correlated values. As a sample, the method of calculating customer-technical interactive score is illustrated here by considering the technical language "Good quality fuel". The relationship of customer voices (that is, drivers' reactions) namely "poor engine condition" and "poor fuel efficiency" against "good quality fuel" is indicated by the symbol ■, whose value is 9. While the relationship of repeated breakdown with "good quality fuel" is denoted by the symbol Δ, whose value is 3. The customer technical interactive scores were calculated as follows.

Formula

$$\text{Customer technical interactive score} = \sum_{i=1}^{n} \text{relationship values between customer voice and technical lanuages} \times \text{expected value of customer voice}$$

where n refers to the number of customer voices.



Note: CTI = Customer technical interactive score; CTL = Correlated weightage of the technical language

Figure 3.
House of quality matrix

Example

$$\text{Customer technical interactive score for “good quality fuel”} = 9 \times 13 + 9 \times 34 + 3 \times 31 = 678$$

In order to visualize the relative weightages, the percentage normalized value of customers technical interactive scores were computed as follows.

Formula

$$\text{Percentage normalized value of customers technical interactive score} = \frac{\text{Customer technical interactive score} \times 100}{\text{Sum of customer technical interactive score}}$$

Example

$$\text{Percentage normalized score of customers technical interactive score the technical voice “good quality fuel”} = (678/25551) \times 100 = 2.65$$

These computed scores are displayed in Table II. The weighted correlated value is calculated by summing the values of correlations. As shown in Figure 3, the weighted correlated value against the technical parameter "good quality fuel" is 3.

In order to visualize the relative weightages of technical correlation, the percentage normalized value of correlated weights were calculated using the following formula.

$$\text{Percentage normalized value of correlated weightage} = \frac{\text{Correlated weightage of the technical language} \times 100}{\text{Sum of correlated weightages}}$$

Example

$$\text{Percentage normalized of correlated weightage against the technical parameter “good quality fuel”} = 9/572 \times 100 = 1.57$$

Both percentage normalized score of customers technical interactive score and percentage normalized value of correlated weightage have been added and entered in the side of correlation matrix of HoQ and are termed as total normalized values.

The fifth author was interviewed to spell out the technical descriptors. These are given code numbers P1, P2, P3, … P32. Though his intension was to prioritise the implication of technical requirements based on percentage normalized value of correlated weightage, he expressed the feasibility of implementing all the technical requirements.

According to the MQFD model (see Figure 2) the fifth author was asked to make strategic decisions to either direct the technical requirements towards the TPM eight pillars implementation or an immediate and direct implementation. Such decisions taken by him are portrayed in Tables III and IV. However these technical requirements could not be implemented in this service station because it is an Indian state government run public sector, which requires decision making by the top level committee by following long democratic procedures. Hence the fifth author was asked to anticipate the result of implementing the MQFD by considering the six maintenance

Table II.
Technical descriptors and their computed scores

Serial number	Technical descriptors	Customer technical interactive score (1)	Percentage normalized value of customers' technical interactive score (2)	Correlated weightage of the technical language (3)	Percentage normalized value of correlated weightage (4)	Sum of (2) + (4)
1	Good quality fuel	678	2.65	9	1.57	4.22
2	Good spare parts	1,458	5.71	21	3.67	9.38
3	Check oil level	1,243	4.86	27	4.72	9.58
4	Check gauges	468	1.83	27	4.72	6.55
5	Change brake lining pads	393	1.54	1	0.16	1.70
6	Check fan belts periodically	118	0.46	9	1.57	2.03
7	Proper tyre inflation pressure	933	3.65	28	4.89	8.54
8	Check for proper function of alternator/dynamo	10	0.04	18	3.15	3.19
9	Routine checkup of battery terminals	119	0.47	9	1.57	2.04
10	Grease periodically	867	3.39	18	3.15	6.54
11	Check eye vision frequently	108	0.42	0	0.00	0.42
12	No intoxication for drivers	673	2.63	1	0.18	2.81
13	Battery water level check	119	0.46	9	1.57	2.03
14	Check radiator coolant	375	1.47	9	1.57	3.04
15	Tighten nuts and bolts frequently	1,452	5.68	9	1.57	7.25
16	Check for oil leak	1,497	5.86	9	1.57	7.43
17	Clean daily	1,242	4.86	10	1.75	6.61
18	Periodic checkup	2,271	8.88	121	21.15	30.03
19	Retread/replace tyres as needed	442	1.73	18	3.15	4.88
20	New and improved suspensions	1,413	5.53	0	0.00	5.53
21	Training maintenance personnel	2,208	8.64	10	1.75	10.39

(*continued*)

Table II.

Serial number	Technical descriptors	Customer technical interactive score (1)	Percentage normalized value of customers' technical interactive score (2)	Correlated weightage of the technical language (3)	Percentage normalized value of correlated weightage (4)	Sum of (2) + (4)
22	Pedal boots (for clutch, brake, gas pedal)	297	1.16	22	3.85	5.01
23	Periodic maintenance	1,969	7.71	87	15.20	22.91
24	Water service	262	1.03	9	1.57	2.60
25	Replace fused bulbs	333	1.30	0	0.00	1.30
26	Halogen bulbs	333	1.30	0	0.00	1.30
27	Ergonomic seats	612	2.39	3	0.52	2.91
28	Rear-view mirror in good position	270	1.06	0	0.00	1.06
29	Better maintenance strategies	1,772	6.94	81	14.16	21.10
30	Seat belts	142	0.56	3	0.52	1.08
31	Body tinkering and painting works	327	1.28	3	0.52	1.80
32	Drivers' rest/sleep	1,147	4.48	1	0.18	4.66

quality parameters of MQFD model. In order to compare the present and future performance, the past data of ten vehicles serviced by the service station were collected. A sample data collected on a vehicle is shown in Table V. The sample calculations of maintenance quality parameters (Chan *et al.*, 2005; Juran and Gryna, 1997) are presented in the subsequent subsections.

Availability

Availability is a measure of what percentage of the total time the vehicle is available for use. It is calculated using the following formula:

Technical languages	Actions to be taken
Periodical check up	Conduct once in every six months
Good spare parts	Always buy spare parts from original equipment manufacturers
Good quality fuel	Fuel should be purchased from government owned depots only
Proper tyre inflation pressure	Tyre inflation pressure has to be checked periodically for each vehicle. The frequency of checking has to be decided as per the recommendation of the manufacturers
Check gauges	Gauges are to be checked by both drivers and maintenance personnel immediately after the engine is started
Check fan belts periodically	Fan belt should not be loose. This has to be checked when the alternator/dynamo is not functioning. Due to this, battery will not get charged. This will result in engine starting troubles
Routine check-up of battery terminals	This has to done once in a week. This is to remove any scale formation
Grease periodically	Greasing has to be done at specified points. This has to be done after every 1,500 kilometers of ride. The purpose of greasing is to prevent wear and tear of machinery parts and severe vibrations
Battery water level check	This can help to enhance the life of the battery
Check radiator coolant	This avoids the corrosion of aluminum parts and hence the life of the waterpump and cylinder head assembly can be improved. The frequency of checking is once in every week
Retread/ replace tyres as needed	Tyres have to be replaced for every 55,000 to 60,000 kilometers. Retreading has to be done after 25,000 kilometers or when tyre is worn out which ever is earliest
Replace fused bulbs	Replacement of fused bulbs and other electrical accessories has to be done when they fail
Body tinkering and painting works	This has to be done according to the decision of the competent authority which will be based up on the situation or body condition
Pedal boots (for clutch, brake and gas pedal)	This has to be done as a routine maintenance practice
Check for proper function of alternator/dynamo	Fan belt should not be loose. This has to be checked when the alternator/dynamo is not functioning. Due to this, battery will not get charged. This will result in engine starting troubles
Halogen bulbs	It is used for visible lighting. Replacement has to be done as and when bulbs fail

Table III. Technical languages which are not required to pass through the TPM pillars

Technical languages	Actions to be taken
Training maintenance people	When a new vehicle is purchased, training should be imparted to drivers/maintenance personnel. They should be deputed to attend those training sessions which will be conducted by the authorize dealers. This is achieved by the pillar "education and training"
Check for oil leak	This has to be checked daily before the vehicle is being put into use. This has to be done through the pillar "education and training"
Tighten nuts and bolts frequently	Everyday before starting the vehicle, nuts and bolts are to be checked and if any looseness found they are to be tightened. This has to be done by the implementation of the pillar "autonomous maintenance"
Check oil level	This has to be implemented by the pillar "autonomous maintenance"
Change brake lining pads	Checking of brakes has to de done when there are complaints from the drivers. In addition to that, break lining pads are to be replaced once in every 20,000 kilometers of running. It has to be done by implementation of the pillar "planned maintenance"
Check eye vision of the drivers frequently	Drivers have to ensure that their eye vision is good. They have to have a check-up every year. In addition to that, drivers above the age of 40 are needed to complete health checkups every year. This has to be done by implementation of the pillar "safety, health and environment"
Ergonomic seats	The seat designs of drivers are to be changed as per the ergonomics requirements. In addition, drivers should be instructed to use seat belts. This has to be implemented by the pillar, "safety, health and environment"
Drivers' rest/sleep	Drivers are advised to avoid night driving as far as possible, especially during peak sleeping hours. This has to be implemented by the pillar, "safety, health and environment"
Rear-view mirror in good position	This has to be adjusted by the drivers before starting the engine. This has to be implemented by the pillar, "autonomous maintenance"
No intoxication for drivers	Drivers are instructed to avoid alcohol. This has to be implemented by the pillar "education and training"
Clean daily	Vehicles have always to be clean. For that daily cleaning is essential. Cleaning has to be done by drivers. Extreme care has to be taken in the conditions of wind screen and glasses
Periodic maintenance	This has to be executed in the interval of every three months. This is very important in the case of vehicles which are used in hilly terrains. This has to be implemented by the pillar, "planned maintenance"

(*continued*)

Table IV. Technical languages, which are required to pass through TPM pillars

Technical languages	Actions to be taken
Seat belts	Drivers are instructed to use seat belts. This has to be implemented by the pillar, "education and training"
Better maintenance strategies	Maintenance personnel should be imparted training once in every six months. They should be trained about fuel economy, economic speed, conducting of special classes by Indian oil corporation adds a lot in this regard. Their theme includes economic usage of fuel and lubricants. People are deputed for the course in every six months. This has to be implemented by the pillar, "education and training"
Water service	It has to be done in every 1,600 kilometers. This has to be implemented by the pillar, "planned maintenance"
New and improved suspensions	This has provided good cushioned effect for both drivers as well as passengers. This has to be implemented by the pillar, "safety, health and environment"

Table IV.

Serial number of the vehicle	Date of arrival	Date of release	Downtime (days)
1	*2003*		
	20 March, 2003	20 March, 2003	1
	02 June, 2003	19 June, 2003	18
	28 July, 2003	28 July, 2003	1
	2004		
	20 January, 2004	13 February, 2004	24
	19 April, 2004	04 May, 2004	16
	22 July, 2004	04 August, 2004	13
	01 September, 2004	08 September, 2004	8
	29 November, 2004	30 November, 2004	1
	28 December, 2004	28 December, 2004	1

Table V.
A portion of vehicle maintenance data

$$\text{Availability} = (\text{Scheduled running time} - \text{Down time})/(\text{Scheduled running time})$$

For example, for vehicle 1 during the year 2003:

$$\begin{aligned}\text{Availability} &= [365\ \text{days} - (1 + 18 + 1)\ \text{days}]/365\ \text{days} \\ &= 94.98\%\end{aligned}$$

Mean down time (MDT)

MDT is the average down time of the vehicle. That is, the average time a vehicle would be out of service during a specified year once it breaks down or is brought for service. It will be generally the sum of down time and idle time.

$$\text{MDT} = \text{Total down time/Number of breakdowns or service entries}$$
$$= -10\text{mm} = \sum(\text{Down times})/(\text{Number of down times})$$

For vehicle 1 in 2003:

$$\text{MDT} = (1 + 18 + 1)\ \text{days}/3$$
$$= 6\ \text{days}$$

Mean time between failures (MTBF)

MTBF is the average time a vehicle would run trouble-free before experiencing any sort of failure. In our situation, information was available only regarding the cases of failure where the vehicle was brought into the workshop for maintenance. Hence, this was assumed accordingly.

$$\text{MTBF} = \sum(\text{TBF})/(N_f + 1)\ \text{where}$$
$$\text{TBF} = \text{Time between failures}$$
$$N_f = \text{Number of failures}$$

For vehicle 1 in 2003:

$$\text{MTBF} = (80 + 72 + 39 + 173)\ \text{days}/(3 + 1)$$
$$= 92\ \text{days}$$

Mean time to repair (MTTR)

MTTR is the average time taken to repair a vehicle once it is brought into service.

It is given by the following formula:

$$\text{MTTR} = \text{Total repair time/Number of workshop visits}$$

In this workshop, we were unable to find data required to find total repair time. Hence, it was decided to take the time to repair as the amount of time the vehicle is laid back inside the workshop. This made MTTR equal to MDT.

Overall equipment efficiency (OEE)

OEE is an effective way of analyzing any vehicle. It is a product of availability, performance rate and quality rate, which are measures of equipment losses (Jonsson and Lesshammar, 1999). Thus, overall effectiveness of the vehicle was considered the ultimate tool in the measuring the success of TPM implementation in the company. It is given by the following formula:

$$\text{OEE} = \text{Availability} \times \text{Performance rate} \times \text{Quality rate}$$

Here, Performance Rate was given an assumed constant value of 0.90 and Quality Rate was given a value of 0.95.

Using these values, OEE for vehicle 1 in the year 2003 was calculated as follows:

$$\begin{aligned} OEE &= 94.98 \times 0.90 \times 0.95 \\ &= 85.48\% \end{aligned}$$

Like the above, the values of maintenance quality parameters concerning the remaining nine vehicles were also computed. The fifth author was shown these values Then he was asked to imagine that MQFD was implemented and forecast the values for the year 2005. Those values (both computed and forecast) are shown in Table VI. As indicated, he anticipates improvement in maintenance quality of vehicles 1-5. He expects the retainment of maintenance quality values for vehicles 6-10. The reason he cites is that these vehicles are new and retaining the previous year's maintenance quality itself is a major achievement. Finally he was asked to declare the anticipated outputs of MQFD implementation. According to his forecast, there will be 5 percent improvement in maintenance quality and 20 percent increase in profit (due to less expenditure on maintenance activities). He is also confident that core competence will get upgraded from the current level of 2 in the Likert's scale of range 0-10 to the level of 7. Further he expects that the goodwill of the service station will enhance from the current level of 4 in the Likert's scale of range 0-10 to the level of 8. According to him, the core competence will be revealed through enhanced skill level of both maintenance staff and drivers, increased awareness over new maintenance methods and reduced number of breakdowns. The goodwill is revealed through increased owner satisfaction, reduced delivery time of vehicles, drivers' satisfaction and saving in fuel cost. These benefits closely coincide with the theoretical drawn predictions shown in Figure 1.

Conclusion and scope for future work

Although maintenance engineering field had been dominant for several decades, its importance was highly enhanced due to the emanation of TPM principles. Before the evolution of TPM principles, maintenance engineering field was isolated from holistic operational performance of organizations. According to this approach, only technical aspects of maintenance engineering were adopted by personnel working in maintenance engineering department (Dekker, 1996; Sherwin, 2000). This approach also deviated maintenance engineering function from the main stream of organizational performance. On presumably realizing the importance of infusing TPM into the organizational working, Nakajima (1993) contributed TPM by linking maintenance engineering and total quality control principles. According to the current literature, the ideal goal of TPM is to nourish the synergic benefits of TQM and maintenance engineering (Hansson and Backlund, 2003). As a means of achieving goals, various TQM strategies are infused in TPM principles. Yet few TQM strategies are yet to be infused in TPM field. One among them is customer voice adoption. In the field of TQM, QFD is used to nourish customer appraisal. However the situation is different in TPM field wherein the sign of customer voice adoption is missing. In order to overcome this research and practice lacuna, the MQFD model is proposed in this paper. The implementation possibility of MQFD was checked in an Indian state government run Public sector service station. The reactions of the practitioners were very encouraging to infer that MQFD would be a feasible model for successfully implementing it and nourishing the synergic benefits of QFD and TPM. Future

Table VI.
Tangible parameters to measure the success of MQFD

Serial number of the vehicle	Year	Availability in percentage	MDT (days)	MTBF (days)	OEE In percentage	Remarks
1	2003	94.98	6	92	85.48	Slightly old
	2004	82.97	10	50	74.67	
	2005 (Anticipated)	96.00	5	110	90.00	
2	2003	96.16	7	97	86.54	Slightly old
	2004	86.39	10	59	77.75	
	2005 (Anticipated)	98.00	5	120	92.00	
3	2003	99.27	1	72	89.34	Slightly old
	2004	97.72	3	89	87.95	
	2005 (Anticipated)	99.27	1	72	89.34	
4	2003	87.26	12	74	78.53	Slightly old
	2004	92.24	10	93	83.02	
	2005(Anticipated)	95.00	5	95	88.00	
5	2003	82.42	16	75	74.18	Old
	2004	77.81	41	142	70.03	
	2005(Anticipated)	82.42	16	75	74.18	
6	2003	97.49	5	147	87.74	Old
	2004	99.18	3	222	89.26	
	2005(Anticipated)	99.18	3	222	89.26	
7	2003	89.68	6	54	80.71	New
	2004	99.91	1	121	89.92	
	2005 (Anticipated)	99.91	1	121	89.92	
8	2003	97.35	2	75	87.62	Very New
	2004	99.82	1	82	89.84	
	2005 (Anticipated)	99.82	1	82	89.84	
9	2003	99.95	1	190	89.96	New
	2004	91.55	5	53	82.40	
	2005 (Anticipated)	91.55	5	53	82.40	
10	2003	89.50	10	81	80.55	New
	2004	95.75	4	69	86.18	
	2005 (Anticipated)	95.75	4	69	86.18	

researchers may gather the support of practitioners implementing MQFD in various companies belonging to different industrial sectors. Those kind of management committed and supported practical studies would reveal the path ways for successfully implementing MQFD model. This venture would provide advanced solutions for enhancing maintenance quality of both equipment and products.

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