Integration of Total Quality Management with Total Productive Maintenance to develop Maintenance Quality Function Deployment model and its implementation study in food industry

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Abstract. In today's modern and highly competitive world, the quality of products as well as the quality in maintenance is of great importance. For that, the involvement of customers is very necessary. To convert these customers' vague languages into technical data, a tool called Quality Function Deployment (QFD) is available in Total Quality Management (TQM). But in order to have quality in maintenance, no such tools or techniques are not available in Total Productive Maintenance (TPM) model. So, a model called Maintenance Quality Function Deployment (MQFD) was developed by incorporating TQM with TPM. Model study was carried out in a food industry; especially in an ice cream industry and suggested action plans for the implementation process for the quality enhancement was done through this study. Details about the machineries involved in the making of the food have been collected and processed for TPM parameter calculations. In food industry the MQFD model is not implemented yet. So, a model study in the food industry is very much useful especially in an ice cream industry due to the fact that, it is one among the most consumed food product all over the world.

Keywords: MQFD, TQM, TPM, QFD, Quality management, Maintenance
Abbreviations – QFD – Quality Function Deployment, TQM – Total Quality Management, TPM – Total Productive Maintenance, HOQ – House of Quality, MQFD – Maintenance Quality Function Deployment, MTBF - Mean Time Between Failure, MDT - Mean Down Time, MTTR - Mean Time To Repair, OEE - Overall Equipment Efficiency

1. Introduction
In today's global and highly competitive market, identification of customer voice or requirements and simultaneous designs of multiple products/services are very important issues of any business. In Total quality management (TQM), Quality Function Deployment (QFD) is well established as a powerful tool to find out the Voice of Customer (VOC), but in Total Productive Maintenance (TPM) such tool is not available to find out the VOC. In this direction, by integrating QFD with TPM a new model named MQFD is derived to resolve this
problem. In order to employ MQFD model in an ice cream processing industry integrated QFD of TQM with TPM.

The efficient ways and implementation strategies to manage maintenance has been well described in [1] and the field of maintenance quality engineering evolved in the mid twentieth century [2]. New methodologies and implementation strategies were developed [3]. Researchers started to believe total quality management (TQM) principles have to be interpreted together with total productive maintenance (TPM) and the model was developed [4]. Table 1 and 2 shows articles which report the link of TPM and QFD with other manufacturing strategies. To obtain a better quality in maintenance, Total productive maintenance opens up a way in the field [5]. Capturing customer voice to enhance the quality of product by collecting the voice of customers is required and thereby the maintenance quality also can be improved. A work was proposed by using fuzzy numbers and fuzzy arithmetic which provided great flexibility in decision making [6]. Methodology to carry out MQFD strategy in an industry was discussed in [7]. The approach of integration between quality and maintenance was done in [8]. The importance for carrying out TPM studies in an manufacturing industry and the way by which it could be implemented was revealed in detail [9]. Studied about maintenance parameters and its relationship with manufacturing performance method [10]. Attempted to investigate the nourishing of the synergy of TPM, QFD and AHP and hence, achieving continuous maintenance quality improvement [11]. The process involved in applying QFD and concludes with a section on the importance of integrating quality throughout the value chain by starting with the Voice of Customer (VOC) and working with quality until the positive impact on customer satisfaction is achieved [12] and [13] focused more on quality matrix problem solving. A QFD based model in transportation sector was proposed to enhance service quality of the conveyance [14]. Optimum utilization of resources was assured by the implementation study of proposed model. Investigations were carried out to find out the importance of tolerances given to customer requirements on a specified product [15]. Customer parameters which directly interpret the quality of the product need to be carefully monitored while conducting implementation study on QFD based models.

The purpose of this work is to develop and implement a manufacturing strategy model named MQFD in a dairy industry by integrating TQM with TPM to ensure quality in maintenance parameters and thereby to enhance the quality of the product as well as the profit of the organization.

| Articles       | Contribution                                                                 |
|----------------|------------------------------------------------------------------------------|
| McKone et al. | Have presented a framework for linking TPM with JIT and manufacturing performance |
| McKone et al. | Have presented a framework for linking TPM with environment, organizational and managerial concepts |
| Cua et al.    | Have presented a framework for linking TPM with JIT |
Table 2 Articles reporting the linking of QFD with other manufacturing strategies and principles [4]

| Articles            | Contribution                                                                 |
|---------------------|-----------------------------------------------------------------------------|
| Olhager and West    | An improved version of House of quality and House of flexibility has been presented. QFD and manufacturing principles are linked. |
| Witter et al.       | A model called ‘enhance QFD’ has been presented. The concept of reusability has been linked with QFD. |
| Ginn et al.         | A model interfacing QFD and FMEA has been proposed.                          |

2. Materials and methods

MQFD implementation process was started by identifying customer’s requirements and expectations about the product and their importance. A questionnaire is needed to design to collect the customer’s voice. It should include the various parameters like sensory, mouth feel effect, rheological characteristics about the ice cream so that the feedback of the customers about the product can be obtained. Then after visiting the production manager of the industry the important parameters about the product which affects the quality of the product have to be discussed. After detailed visit, the technical parameters which concern about the quality of the product have to be found out from the literature survey. The importance of each of the technical parameter thus found out and suggested the organization personnel on the effectiveness of the methodology and collected parametric values which are available from the industry. Then the constructed house of quality which customer and technical parameter. Decisions on the technical parameters which need to be undergoing TPM pillar action plan was also discussed. Then it is passed via production sector to check its maintenance quality. Maintenance quality is checked using the parameters such as Availability, OEE, MTBF, MTTR, MDT.

2.1 TPM Pillars

TPM consists of 8 pillars.

1) Autonomous maintenance: Maintenance activities which are done by the operators themselves during the time of their work.
2) Individual improvement: Each and every individual's intention to study and learn during working period so that it may get benefitted to both the individual and the organization.
3) Planned maintenance: Maintenance activities which are actually scheduled and planned so thereby the unexpected breakdown and related problems may not interfere the smooth functioning of the industry.
4) Quality maintenance: It focused about the components and elements which directly affect the quality of the product as well the organization.
5) Initial control/Development management: It provides action plan on the initial involvement of personnel to carry out the process, thus there won’t be any discrepancies.
6) Education and Training: Skills of the operators and other responsible personnel of the organization are very much important in enhancing the quality of product. Skill upgradation activities come under this pillar.
7) Office TPM: It brings the whole administration into the process. Decisions and quality infrastructure provided by the administrators help in the product development.

8) Safety, Health and Environment: Clean and well ordered job locations will certainly help the workers to involve in the process of producing quality products.

3. MQFD Model

MQFD integrates QFD and TPM. The model shown in figure 1, starts with collecting the customer languages. The customer languages are then converted into the technical specifications after the development of House of Quality (HOQ). Then the decisions are made to find which parameters need to be passing through necessary technical requirements and action plans. The decisions which are made for actions requiring maintenance quality improvement will be subjected to TPM implementation. The technical languages are passed through the eight pillars of TPM. The output will reflect in the production environment. Quality in maintenance is ensured by estimating the following parameters.

- Availability
- Mean Time Between Failure (MTBF)
- Mean Time To Repair
- Overall Equipment Efficiency (OEE)
- Mean Down Time (MDT)

A properly run and monitored MQFD process is required to result in improved maintenance, increased profit, upgraded core competence, and enhanced goodwill. Some of the technical languages drawn out of the HOQ are not passing through TPM after the decision making process, will indicate the revised targets for the overall business performance improvement.

![Figure 1. MQFD Model [8]](image)

4. Development of HOQ

Six main sub matrices are there for constructing HOQ.

- Matrix 1 - Customer parameters language matrix
- Matrix 2 - Ranking matrix of customer languages
- Matrix 3 - Technical parameters matrix
- Matrix 4 - Customer and Technical parameters relationship matrix
- Matrix 5 - Ranking matrix of technical parameters

Mean Time Between Failure (MTBF)
Mean Time To Repair
Overall Equipment Efficiency (OEE)
Mean Down Time (MDT)
Customer parameters are interpreted with the technical parameters of the product been in concern. Then the data collected from the customers, industry, distributors as well as the organization which are the main stakeholders of the output, was analyzed and values of each and every parameter was included in the completion of the quality matrix. From the HOQ and on the basis of the ranks of each parameter, decisions were made to pass the important technical parameters through the TPM pillars which is the next step towards the MQFD model implementation. HOQ matrices, developed correlation matrix and relationship matrix are shown in figure 2, figure 3 and figure 4. Technical parameters and customer parameters are given in Table 3 and Table 4.

### Table 3. Technical parameters

| Technical Parameters            | Protein content | PH value | Proper homogenization | Shelf life |
|--------------------------------|-----------------|----------|-----------------------|------------|
| Maintain stabiliser content    | Maintain sugar  | Lactose  | Proper mixing of      | Regulate   |
| content                        | content         | recrystallisation | ingredients | fat        |
| Non – Microbial action         | Non – Microbial | Air      | Cell distribution     | In process |
| Carbohydrate content           | Carbohydrate    | Amount of | Temperature of ice    | Useful     |
| content                        | content         | air added | cream making          | testing     |
| Amount of Skimmed milk powder  | Amount of Skimmed | Fat     | Proper weighing       | Employee    |
| (SMP)                          | milk powder     | stabilisation | methods              | awareness  |
| Milk – Solids – No – Fat (MSNF)| Milk – Solids – | Proper   | Proper aging          | Include     |
| %                              | No – Fat (MSNF) | pasteurization | process              | ice cream  |
|                                 |                 |          |                       | recipes     |

### Table 4. Customer parameters

|                        | Sensorial characteristics | Rheological characteristics | Mouth feel effect | Essential product features |
|------------------------|---------------------------|------------------------------|--------------------|----------------------------|
| Flavour                | Flavour                   | Gumminess                    | Smoothness         | Quantity                   |
| Firmness               | Firmness                  | Viscosity                    | Sweetness          | Scoop ability              |
| Creaminess             | Creaminess                | Consistency                  | Sandiness          | Overrun                    |
| Overall Appearance     |                           |                              | Melting feel       | Addition of food items     |
| Texture                |                           |                              | Eating             | Colour                     |
|                        |                           |                              |                    | Price                      |
|                        |                           |                              |                    | Packing design             |
|                        |                           |                              |                    | Reservation                |
|                        |                           |                              |                    | Certification              |
|                        |                           |                              |                    | Recipes                    |
Figure 2. HOQ Matrices [8]

Figure 3. Correlation matrix

Figure 4. Relationship and ranking matrix
Using these data customer technical interactive scores and correlated scores of technical language are calculated. Customer technical interactive score can be calculated by summing up all the relationship values between customer voice and technical languages after multiplying it with expected value of customer voice.

\[ \text{e.g. Matrix 1 score for 'regulate fat content' = } 9 \times 44 + 3 \times 37 + 3 \times 42 + 1 \times 63 + 3 \times 46 + 3 \times 18 + 9 \times 35 + 9 \times 42 + 3 \times 51 + 3 \times 27 + 9 \times 70 + 9 \times 43 + 9 \times 38 + 3 \times 69 + 1 \times 54 + 3 \times 84 = 3687 \]

\[ \% \text{ normalized value of scores of matrix 1 = } \frac{\text{Score of matrix 1}}{\text{sum of scores}} \times 100 \ (1) \]

\[ \text{e.g. } \% \text{ normalized value of score of matrix 1 for the customer parameter 'regulate fat content' = } \frac{3687}{74559} \times 100 = 4.9 \]

\[ \% \text{ normalized value of scores of matrix 3 to correlate technical parameters is done by (2). } \]

\[ \% \text{ normalized value of score of matrix 3 = } \frac{\text{Score of matrix 3}}{\text{sum of scores}} \times 100 \ (2) \]

\[ \text{e.g. for technical parameter 'regulate fat content' (109/1882) \times 100 = 5.8} \]

\% normalized value of scores of matrix 1 and \% normalized value of scores of matrix 3 have been summated and included in correlation matrix. HOQ was constructed using every values each parameter. Technical descriptors and their computed scores are given in Table 5.

| Technical Descriptors                  | Matrix 1 score (1) | % normalized value of matrix 1 score (2) | Matrix 3 score (3) | % normalized value of matrix 3 score (4) | Correlated value =2+4 |
|----------------------------------------|-------------------|----------------------------------------|-------------------|----------------------------------------|----------------------|
| Regulate fat content                   | 3687              | 4.9                                    | 109               | 5.8                                    | 10.7                 |
| Protein content                        | 1252              | 1.7                                    | 54                | 2.9                                    | 4.6                  |
| Maintain stabiliser content            | 3943              | 5.3                                    | 42                | 2.2                                    | 7.5                  |
| Maintain sugar content                 | 3242              | 4.3                                    | 74                | 3.9                                    | 8.2                  |
| Carbohydrate content                  | 835               | 1.1                                    | 45                | 2.4                                    | 3.5                  |
| Amount of Skimmed Milk Powder (SMP)    | 3597              | 4.8                                    | 95                | 5                                      | 9.8                  |
| Milk Solids – No – Fat % (MSNIF)       | 2713              | 3.6                                    | 67                | 3.6                                    | 7.2                  |
| PH value                               | 817               | 1.1                                    | 33                | 1.7                                    | 2.8                  |
| Lactose recrystallisation              | 1950              | 2.6                                    | 33                | 1.7                                    | 4.3                  |
| Non microbial action                   | 619               | 0.8                                    | 80                | 4.2                                    | 5                    |
| Amount of air added                    | 6822              | 9.1                                    | 89                | 4.7                                    | 13.8                 |
Technical Descriptors | Matrix 1 score (1) | % normalized value of matrix 1 score (2) | Matrix 3 score (3) | % normalized value of matrix 3 score (4) | Correlated value =2+4
---|---|---|---|---|---
Fat instabilisation | 2410 | 3.2 | 49 | 2.6 | 5.8
Proper pasteurization | 3979 | 5.3 | 120 | 6.4 | 11.7
Proper homogenization | 3655 | 4.9 | 109 | 5.8 | 10.7
Proper mixing of ingredients | 4929 | 6.6 | 118 | 6.3 | 12.9
Air cell distribution | 3102 | 4.1 | 36 | 1.9 | 6
Temperature of ice cream making | 2700 | 3.6 | 100 | 5.3 | 8.9
Proper weighing methods | 2433 | 3.3 | 94 | 5 | 8.3
Proper aging process | 3143 | 4.2 | 118 | 6.3 | 10.5
Shelf life | 5094 | 6.8 | 58 | 3.1 | 9.9
Packaging size | 2736 | 3.7 | 43 | 2.3 | 6
In process inspection | 2660 | 3.6 | 118 | 6.3 | 9.9
Useful testing procedures | 2848 | 3.8 | 72 | 3.8 | 7.6
Employee awareness | 3611 | 4.8 | 107 | 5.7 | 10.5

4.1 Implementation of technical requirements

Decisions have to be made in regard with the ranking of parameters which obtained from HOQ matrix. Those decisions with the consultation of the organization personnel about those significant parameters which need to pass through the TPM pillars were made. Some of the insignificant parameters which recognized from the HOQ were not passed through the TPM, because when it compared with the significant parameters on the basis of ranking, those had a very little influence on the quality of the product. Separate action plan was prepared for every parameter which are considered to be significant. Among those one of them is explained by Table 6. Five of the technical parameters were not passed through the TPM pillars - 'Protein content', 'Carbohydrate content', 'MSNF %', 'pH value', 'Lactose recrystallisation', the rest have been passed via TPM pillars.
Table 6. Action plan recommended in TPM pillars for technical parameters

| Proper pasteurisation | Action Plan |
|-----------------------|-------------|
| Autonomous Maintenance | A proper schedule should be made for maintenance. Cleaning, lubrication, tightening of the pasteuriser should be done by the equipment operators themselves. |
| Individual improvement | Employees should their own way of maintaining the pasteuriser so that no breakage of the operation of the equipment could occur. |
| Planned maintenance | Proper schedule of maintenance of the equipment which has to be carried out daily, weekly, and monthly as well as yearly and it should be planned prior to the operation of the equipment, so that the working of the equipment is not disturbed. |
| Quality maintenance | By means of proper inspection and maintenance, pasteuriser down time can be reduced. This helps the better schedule of the equipment. |
| Initial control/Development management | Suitable target has to be made in order to avoid rush of making ice creams of different order size by proper time management. Thus reduces the machine downtime. |
| Education and training | Staff learning programs should be conducted with in the organization to upgrade skills of the operators also training about how to operate the pasteuriser and awareness should be given to the employees so that any danger can be easily handled also minor repairs can be done by themselves. |
| Office TPM | By means of modern instruments like digital thermometers the temperature of the operation of pasteuriser can be easily maintained. Pasteurising temperature range is 30 - 70 degree celsius. Also using new and very precise instruments, the maintenance can be done fast. |
| Safety, health and environment | Working environment should be clean so that it provide better health and safety of the employees. Safety dresses like gloves, hair clothes, etc. should be given to the workers. |

5. Analysis of maintenance parameters

Efficacy of TPM implementation was done by the analyzing maintenance parameters such as time for failure and repair, efficiency of machines, down time, availability of machines. The values of each parameter for three machines (namely, pasteurizer, homogenizer, and Aging Vat) for a year was provided by the machine supervisors and analyzed it to decide on the quality of maintenance for the improvement of the product quality.

5.1 Calculation of maintenance parameters

Parameter 1 - Availability is a estimate of accessibility of machine's total useful time during the making of product

\[
\text{Availability} = \frac{\text{Scheduled running time} - \text{Down time}}{\text{Scheduled running time}} \times 100\%
\]

e.g., for Pasteuriser during the month March is given by

\[
\text{Availability} = \frac{8820 - 1740}{8820} = 80.27 \%
\]
Figure 5. Availability of machines

Parameter 2 - Mean time between failures (MTBF) is the mean time the equipment would work in between consecutive failures (Figure 6).

\[ \text{MTBF} = \frac{\text{Summation of time between failures}}{\text{Number of failures}} \]

For Pasteuriser in March,

\[ \text{MTBF} = \frac{7080}{1} = 7080 \text{ mins} \]

Parameter 3 - Mean down time (MDT) is the mean time of the machine break down and idle time due to some unplanned failures happened to machines as well as lack of proper maintenance. (Figure 7)

\[ \text{MDT} = \frac{\text{Total down time}}{\text{Number of breakdowns}} \]

\[ \text{MDT} = \frac{29}{31} = 0.94 \text{ hrs} \]

Parameter 4 - Mean Time to Repair (MTTR) is the average time for a machine repair or the time for equipment service. (Figure 8)

\[ \text{MTTR} = \frac{\text{Total repair time}}{\text{No. of break down}} \]

\[ \text{MTTR} = \frac{12}{1} = 12 \text{ hrs} \]
Parameter 5 - Overall equipment effectiveness (OEE) is an effective way of analyzing any machine. It is a product of availability, performance rate and quality rate.

\[
\text{Overall effectiveness} = \text{Parameter 1} \times \text{Rate of performance} \times \text{Rate of quality} \quad (\text{Figure 9})
\]

\[
\text{OEE} = 0.802 \times 0.9 \times 0.95 = 68.63 \%
\]

Figure 9. Overall Equipment Efficiency (OEE) of machines

Forecasting of the computed and interpreted action plans mentioned in the work would benefit the industrial organisations to enhance their quality of their product by passing through maintenance parameters.

5. Results and Discussions

For integrating TQM with TPM, details like machines involved and its run time, down time, maintenance details, idle time, product characteristics, technical parameters which favors the quality interpretation were collected. A questionnaire was designed based on these characteristics of the product and given to 10 distributors for gathering the voices of customers. HOQ construction was completed by correlating customer and technical languages. Strategic decision was taken after discussing it with the production manager that which of the parameters should go through TPM pillars and which of them don’t. Technical requirements were implemented by allotting proper action plans through TPM pillars. The results are directed to the production system and evaluated the results using the parameters namely (OEE, MTBF, MTTR, MDT and availability) of machines.

6. Conclusion

Due to the global competition developed in the recent era, new models or techniques are necessary for the smooth functioning of an industry. Quality is one of the main aspects that have to be considered by the industry ahead to satisfy the customer satisfaction. So, MQFD model is seemed to be a good method that can be introduced in many industries. Although QFD and TPM are appearing to be separate entities, the contributed MQFD model proves to be an appropriate device to exploit and share the beneficial features of them. It was found that the MQFD implementation has necessary importance in the production field. By incorporating customer views using HOQ matrix of QFD, the quality and efficiency of TPM can be enhanced to a much larger extent. The model thus developed will certainly be a great asset in the production sector, especially in the food industry where quality and maintenance is of great importance.

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