Cost and benefit analysis of implementing TFMEA in tea industry: a case study

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Abstract: Tea is an aromatic drink commonly consumed by the people worldwide. Tea manufacturers face a serious threat in controlling the failures in its manufacturing process. Failures in the manufacturing process affect the quality of the tea produced. The cost of the tea varies with the quality of the tea. The tea manufacturers are more concerned about the internal failure cost incurred in its manufacturing process as it determines the cost and quality of the tea. In this background, a new approach namely cost-based total failure mode and effect analysis (CTFMEA) was applied in the research reported in this paper. In this research, a maiden attempt is made to implement this new approach by conducting a case study in tea manufacturing company. After implementing TFMEA technique its cost benefit analysis was conducted. The outcome of this research indicated that through the application of CTFMEA, the quality of the tea could be improved by reducing the failures thereby assuring cost benefits to the tea manufacturers.

Keywords: tea manufacturing; internal failure cost; continuous quality improvement; total quality management; TQM; fault tree analysis; FTA; failure mode effect analysis; FMEA; CTFMEA; cost benefits.

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1 Introduction

Tea is a beverage consumed by majority of people in the world. Tea is considered as a healthy and refreshing beverage worldwide. It is claimed that consumption of tea facilitates to prevent heart diseases, cancer, and other serious neurological disorder among the people. Tea is considered as an effective agent in the prevention and treatment of neurological diseases, especially degenerative diseases like Alzheimer and multiple sclerosis. Besides, polyphenols in tea helps in keeping the parts of the brain healthier, regulating the cognitive skills of a person. The antioxidants and other chemical

composition in tea are highly beneficial to the people who consume it. Because of these favourable reasons, demand for tea is increasing in the world. Hence, the tea manufacturers are highly financially benefited. The financial value of tea is based on the quality of tea which helps the manufacturers of tea to compete and sustain in the competitive market. For flawless and high performance, organisations intentionally prefer total quality management (TQM) to gain competitive advantage (Al-Refaie and Hanayneh, 2014). TQM is not a simple measurement because it expands beyond statistical process control in order to embrace a wider scope of management activities and hence a comprehensive management system which focuses on customers, continuous improvement, involvement of every one and maximising the performance of processes (Ramesh and Ravi, 2013). Therefore, it has to be made as a culture in the organisations since the culture of excellence (CoE) and knowledge sharing (KS) are considered to be vital factors for organisation to thrive in the competitive global market (Rezaei et al., 2016) for which the managers' role is considered to be vital (Wahudi et al., 2016). Therefore, the executives in charge of the concerned departments were considered and their opinions were obtained in this study.

Failure mode effect analysis (FMEA) is one of the TQM techniques which could be effectively implemented to find out the failures in manufacturing process in order to prevent the occurrence of failures for improving the quality of tea because such failures are the main cause for deterioration of quality of tea. Few commonly identified defects due to failures in the tea manufacturing process are casehardening, stewing, burnt, bakey, high fired, and raw (Ebenezer et al., 2011; Hafezi et al., 2006; Sharma, 2000; Britt, 2007).

Many researchers have studied the use of FMEA to prevent the occurrence of failures in manufacturing organisations (Estorillo and Posso, 2010; Segismundo and Miguel, 2008; Oprime et al., 2011; Xiao et al., 2011). However, during the recent years a few researchers have come out with an opinion that FMEA does not effectively involve all departments and personnel. Further, there has been an apprehension that evaluating risk priority number (RPN) which is used to estimate the intensity of failures seemed to be cumbersome and does not indicate the accurate value of importance of the failure and hence the purpose is not served fully. In order to overcome such drawbacks, a few researchers have attempted to bring out few advanced techniques. One among them is total failure mode effect analysis (TFMEA) which was proposed by Devadasan et al. (2003) and was considered while pursuing the research reported in this paper.

The TFMEA essentially involves all the departments and personnel while analysing the failures and preventing their recurrence. This ensures that each failure is prevented from recurrence from a total point of view of the organisation. Besides, TFMEA replaces RPN approach with single ratings to indicate the seriousness of failures. In this background, the research works reported in Devadasan et al. (2003) and Ebenezer et al. (2011) were studied. The outcome of these studies revealed that so far cost and benefit aspects have not been considered in their research studies involving the application of TFMEA. This research gap motivated the authors to conduct this research study involving cost-based total failure mode effects analysis (CTFMEA) in a tea manufacturing company considering the cost and benefit aspects and to overcome this research gap. The details of this research are presented in the subsequent sections of this paper.

2 Literature review

The concept of TFMEA has been derived from the FMEA model. Hence, it was felt that research studies on FMEA may help in framing the concept of this study. Therefore, a literature review was conducted to gather information and knowledge about the techniques developed by the researchers by linking FMEA with other techniques, tools and approaches. The information and knowledge thus gathered are briefly described in this section.

Ginn et al. (1988) have proposed a technique integrating quality function deployment and FMEA technique. On implementing these QFD-FMEA techniques jointly in Ford Motor Company, this entry rated technique facilitated to reduce the failures. Price and Taylor (2002) proposed a new model called automated multiple failures FMEA which helps to carry out analysis of a large number of failure combinations. The most significant combinations that lead to the derivation of results have also been highlighted in their study. Teoh and Case (2004a, 2004b) developed a model which makes use of knowledge modelling method wherein, functional reasoning techniques are employed to assist to analyse the failures by referring to historical data. Arvanitoyannis and Varzakas (2006) integrated hazard analysis critical control with FMEA, cause and effect analysis and Pareto diagram. This integrated approach was applied to analyse the critical control points in the manufacturing of the potato chips to reduce the failures in the process. Further, Arvanitoyannis and Varzakas (2009) applied the FMEA model in conjunction with cause and effect analysis for carrying out the risk assessment of octopus processing for finding out the corrective actions. Ahsen (2008) designed an improved model known as cost-oriented FMEA in which the severity of failures was denoted in terms of costs. Colvin et al. (2008) developed a model called timed FMEA which suggests a new approach for supporting FMEA in time critical systems.

Ebenezer et al. (2011) discussed the tactical steps to gain the acceptance of TFMEA programme among the labourers and managerial personnel of tea manufacturing company using a hypothetical case study and concluded by pointing out that real-time case studies are required to be carried out for assessing the practicality of implementing TFMEA programme in the tea industry. Krishnaraj et al. (2012) have conducted literature review to draw synergy out of TFMEA along with the unconquered areas of the TFMEA. As mentioned in the previous section, in these researches, cost benefit of implementing TFMEA was not considered. In order to overcome this research gap, after implementing TFMEA in a tea manufacturing company, its cost-benefit was analysed. Devadasan et al. (2003) proposed TFMEA technique by incorporating eight changes in the FMEA technique. Brucely et al. (2016) have studied the implementation of TFMEA using fuzzy inference system (FIS) for the production of high quality tea. The objective of their research is to improve the profit of the tea industry by enhancing the product quality through minimising the occurrence of failures. Finally, they concluded that the TFMEA method prohibits failures to enhance the system quality effectively. Sutrisno et al. (2016) have attempted to integrate SWOT analysis into the FMEA to improve corrective action decision making considering the influence of factors relating to the business environment which may support or derail improvement efforts. The variables that were taken under SWOT are the benefit, cost, opportunity, risk and organisational readiness index (BCOR2) approach in order for the FMEA team to select from competing corrective actions and found this new model contributed successfully in identifying the appropriate

corrective action towards improvement. Further, Srivatsava and Mondal (2015) have developed a new model called modified failure mode effect and criticality analysis (Mod-FMECA) to identify failure modes, reasons, effects and criticality of system (machine/plant). This validated methodology while using in coal pulverising mill minimised the use of costly predictive maintenance equipments. Another study was done by Mirzaei and Avakhdarestani (2016) by integrating FMEA with fuzzy analytical network process (ANP). In their study, they used fuzzy approach by using linguistic variables that is fuzzy preference priority (FPP) integrated with fuzzy ANP instead of using RPNs in FMEA for determining pair-wise comparisons. This study confirmed the applicability of the model in FMEA under fuzzy environment. Farajiparvar and Mayorga (forthcoming) have done a study using fuzzy failure modes and effective analysis (FFMEA) to address the concept of maintenance policy section (MPS) in order to improve the real equipment condition.

Tippayawong et al. (2017) have investigated the company's value chain activities and current production practice in Thailand's tea industry, using FMEA technique to perform a risk assessment within the manufacturing process weaknesses in order to take corrective actions to improve performance. Further, the reduction of risks improves the performance level of the industry (Trafialek and Kalanowski, 2014). Ashley et al. (2016) have reported that FMEA is a prospective quality assurance methodology which is commonly and increasingly used in healthcare, which helps identify the potential, vulnerable and risks towards remedial actions for better performance. Subash Babu et al. (2014) have used a multistage methodology catering to different failure modes using FMEA for estimating the failure intensity of software. Through this empirical study, certain types of failures were corrected while the test program was in progress and few other failures were corrected at the end of the test program. Takahashi et al. (2016) have studied to avoid errors in the control software in the industrial products which make the consumer and the products' danger. They have proposed a method by repeatedly using FMEA and fault tree analysis (FTA); the control software could be made safe.

A case study was conducted in automobile component manufacturing industry by Senthilmurugan et al. (2016), using TFMEA to reduce the rejection rate of a component called 'U' type clamp. Before applying TFMEA, 10% of the 'U' type clamps produced was rejected due to the misalignment of two holes of this component in this company. As a result of implementing TFMEA technique, a pillar die set was designed and fabricated to prevent this misalignment problem, leading to reduction in the rejection rate from 10% to 5%. Further, Rajan and Pramod (2016) have conducted a study by implementing TFMEA in forging industry to achieve zero failure. The authors, after having gone through the above studies have come to the conclusion that most of the failures in the industry could be reduced by using TFMEA technique, to enhance the quality of the product. Conforming to the conclusion, the authors intended to take a tea manufacturing industry situated in Kerala, South India as a case, which prompted the authors to frame the following objectives.

3 Research objectives

The research objectives thus framed are:

1 Could TFMEA be implemented in tea manufacturing industry to analyse the failures in the manufacturing process?

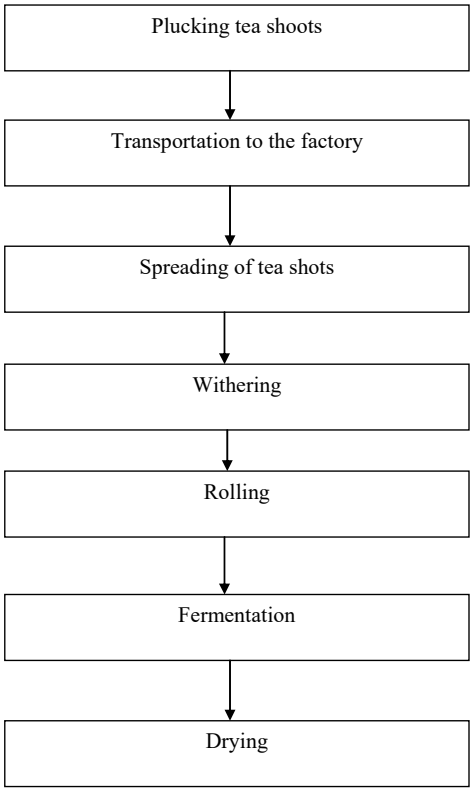
2 Will rectification of failures in the manufacturing process actually improve the quality of the product?

3 Whether cost benefit could be achieved by implementing TFMEA?

4 Case study

In order to accomplish the objectives, the case study being reported here was carried out in a tea manufacturing company located in Idukki district of Kerala State of India. In order to maintain anonymity, the name of this company is referred to here as XYZ. Currently 250 employees are working in XYZ. Out of them, 125 are labourers and are involved in plucking tea leaves and processing them. The remaining employees are engineers and managerial executives. After reaching the factory, the leaves were subjected to seven steps (please see Figure 1) and are usually followed in XYZ to manufacture tea also. The management of XYZ has realised that improving the quality of tea and its manufacturing process is vital, to face the global competition. In this context, XYZ was chosen to implement TFMEA in the production of tea.

Figure 1 Steps in tea manufacturing process



5 Process implementation method

The implementation of CTFMEA was done as a case in a selected XYZ tea industry as prescribed in the TFMEA model. The implementation procedure includes two phases which have been described in the following subsections. To begin with, the top management appointed an engineer as TFMEA programme coordinator. This engineer discussed with the managerial personnel of XYZ industry about the details of TFMEA programme and briefed its capability in improving the quality of tea produced and the process involved. Subsequently, TFMEA was implemented in XYZ in two phases.

5.1 Sampling

A total of 15 executives from the four different departments in the factory were taken as sample by following simple random sampling technique. Following is the sampling frame as shown in Table 1.

Table 1 Department-wise distribution of team members

Sl. no.	*Departments*	*XYZ tea industry*	
		Total staff	*TFMEA team*
1	Production	61	5
2	Maintenance	35	5
3	Quality control	12	2
4	Sales	17	3
	Total	125	15

Source: Primary

In the first phase, TFMEA technique was implemented. In the second phase, cost benefit analysis of implementing TFMEA was analysed. The efforts were taken to implement the activities under these two phases which have been described in the following two sub sections.

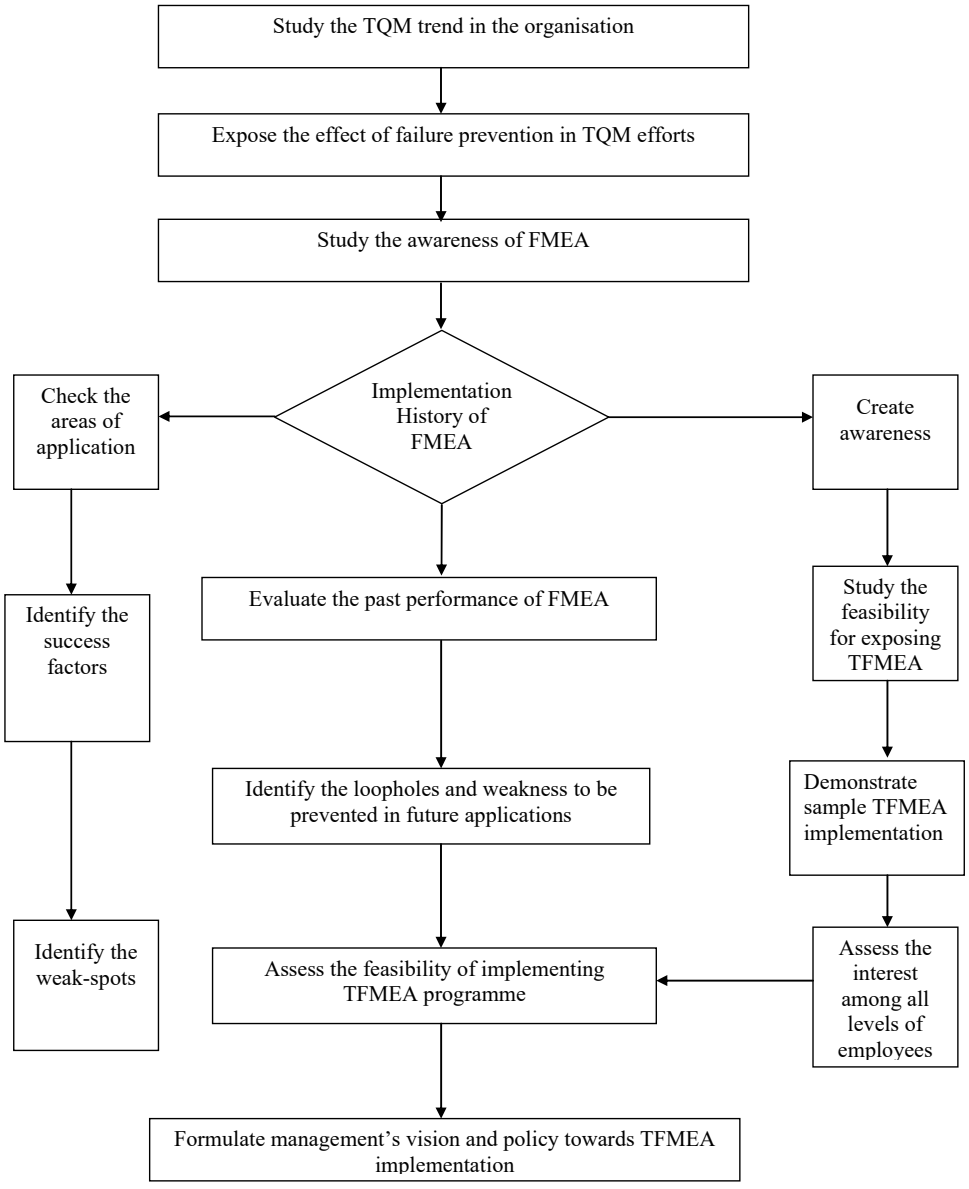
5.2 Implementation of phase 1

As mentioned earlier, in this phase TFMEA was implemented. The activities carried out at XYZ in this regard are described on this section.

5.2.1 Studying the TQM trend in the organisation

To begin with, the commitment of management towards the execution of quality improvement activities at XYZ in the past was assessed. Particularly, this assessment measured the performance level of TQM programme in XYZ. This assessment was carried out by getting feedback using questionnaire (structured with scale of range 0–10) and through conducting direct interviews (one to one discussion) with all level of employees. On calculation, mean score of TQM practice was found to be more than five and hence it was preferred to take a step forward to implement TFMEA programme in XYZ by carrying out the steps enumerated in Ebenezer et al. (2011).

Figure 2 Implementation phase 1



Source: Devadasan et al. (2003)

5.2.2 Exposing of the effects of failure prevention in TQM efforts

The employees of XYZ were trained to realise the importance of failure prevention for effecting continuous quality improvement. Further, the managers were asked to identify the micro and macro failures that occurred in XYZ related to quality improvement journey and were listed. In addition, the data was collected related to the performance of various departments of XYZ and training programmes conducted.

5.2.3 Studying the awareness of FMEA

A study was made to identify any attempts that could have been made to implement FMEA in XYZ. The result of this study revealed that FMEA has so far not been implemented in XYZ.

5.2.4 Creating awareness

Since FMEA has so far not been implemented, different awareness programs of TFMEA to suit various levels of employees of XYZ were conducted. For example, the management was highlighted with failure data and its role in wastage of the resources in terms of cost. Similarly, awareness was created among the lowest level employees regarding deviation in the manufacturing process and making awareness about non-compliance found in the existing tea manufacturing process. Once the awareness creation task was completed, the process of introducing TFMEA tables for rating the causes of failures was started by conducting meetings with managerial personnel and other employees of XYZ. At this stage, any disbelief that existed among managerial and non-managerial personnel was removed by providing appropriate clarification. Overall, this stage created positive impact on implementation of TFMEA technique in XYZ.

5.2.5 Studying the feasibility for exposing TFMEA

After creating the necessary awareness, the feasibility of exposing employees of XYZ to TFMEA technique was studied at all levels. Further, the technical and educational data were collected by conducting interviews at all levels of the employees. From these data, the authors felt that it was feasible to implement TFMEA technique in XYZ.

5.2.6 Demonstrating sample TFMEA implementation

The TFMEA implementation was initiated by demonstrating sample failure (Devadasan et al., 2003). This failure of task was analysed with suitable TFMEA table, which made the management to get confidence towards successful TFMEA implementation. This analysis enabled to extend the development of TFMEA tables with respect to all the failures in XYZ paving way for successful TFMEA implementation.

5.2.7 Assessing the interest among all levels of employees

After implementing the sample TFMEA, the interest about the implementation of TFMEA among the employees were found to be satisfactory. The feasibility report was submitted to the management of XYZ to initiate the journey of TFMEA implementation for minimising the failures.

5.2.8 Formulating management's mission and vision towards TFMEA implementation

After ascertaining the feasibility of TFMEA implementation in XYZ, the vision of management towards implementing TFMEA was framed. The main aim of the mission statement is to meet the customer expectations by producing unique and superior quality

of tea through sustainable business practice. The statement ascribing this vision is presented below.

5.2.9 Vision statement

To be precise, the management's long-term and short-term vision with regard to the prevention of failure was structured during this stage. Management framed the vision during the course of time and according to prevailing situation. In this study, the management took these policy decisions and proposed appropriate roadmap to implement TFMEA programme. Accordingly the vision and mission towards the implementation of TFMEA were approved and carried out.

5.2.10 Mission statement

Likewise the following mission statements were developed:

- to adopt continuous quality improvement practice by eliminating the process failures
- to maintain sustainability through practice of quality management techniques fulfilling corporate social responsibility activities
- to penetrate global consumer market by producing quality products meeting international standards
- to engage the employees committed to the vision of the organisation.

5.3 Implementation of phase 2

As mentioned earlier, while implementing phase 2, TFMEA implementation was followed by the conduct of cost benefit analysis. The activities carried out under this phase are described in this subsection.

5.3.1 Identification of soft areas of TFMEA implementation

The capability and list of quality parameters about the tea and its process involved were discussed with managerial personnel of XYZ who have already acquired sufficient knowledge about the TFMEA programme.

5.3.2 Creating methods and procedures for recording failures

As discussed earlier, the TFMEA programme coordinator requested the employees to initiate the TFMEA programme by listing various defects affecting the quality of tea produced in XYZ. After the defects were listed, the TFMEA coordinator chose the most significant defect by interacting with the team members. The defect thus chosen was 'high fired tea'. Therefore this defect was considered to be the major failure in the production of tea in XYZ.

5.3.3 Developing organisation for implementing TFMEA

A TFMEA team consisting of employees who volunteered to become members of it was formed. Since the management was committed, the TFMEA team formation representing

employees from all the departments was formed in XYZ without any difficulty. The coordinator discussed with TFMEA team members to solve the problem of high fired tea at XYZ.

5.3.4 Initiation of developing of TFMEA tables and brainstorming sessions

The coordinator convened the meeting and explained about the brainstorming technique. Particularly, the coordinator explained the rules of brainstorming session to the TFMEA team members. During the meeting, it was decided to frame the TFMEA table pertaining to the departments namely production, maintenance, quality control, and sales and marketing which are associated with the occurrence of high fired tea defect in XYZ. The coordinator ensured that TFMEA members from the above mentioned departments participated in the meeting.

Figure 3 Modified TFMEA approach for CTFMEA implementation

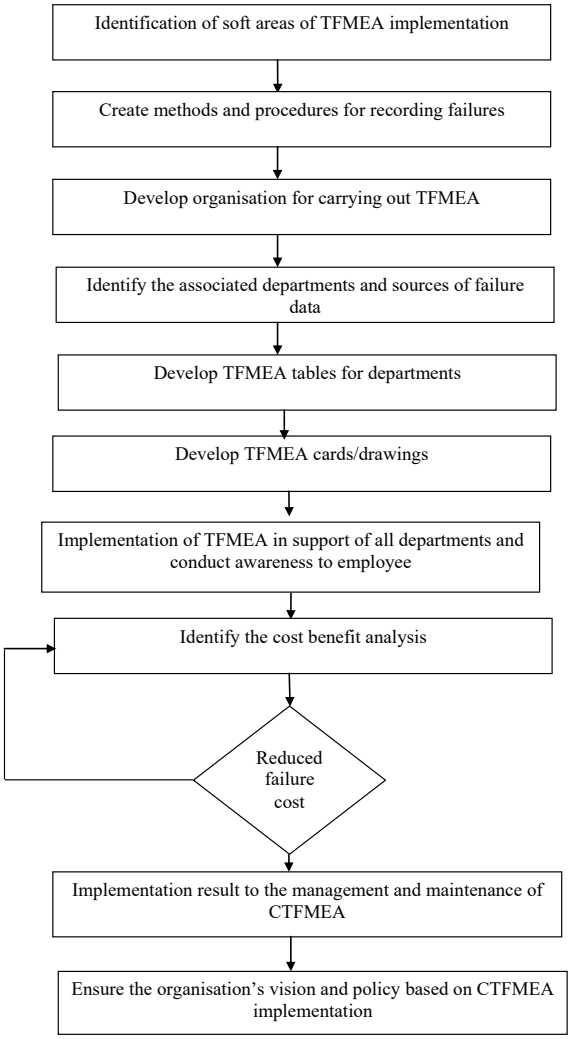


Table 2 TFMEA rating of failures by production department

Process name: Drying								Last update on:	
Members present:								Updated by:	
TFMEA number:								Date:	
Failure mode	*Cause of failure*	*Effects of failure*	*Present control*	*Rating*	*Departments*			*Recommended activities*	*Approved by*
					Q	*M*	*S*		
High fired tea	High inlet air temperature.	Burnt taste of tea	Manual control using thermometer	7	9	5	8	Thermocouple with digital display/sensor to be installed in the chamber.	General manager
	Cold air induction fan not working.			6	8	4	6	Andon alarm signal to be placed, when fan is not working.	
	Fluidised dryer Vibrator not working.			8	9	9	9	Andon alarm signal to be placed, when vibrator is not working.	
	Improper air velocity in the drying chamber.			6	9	8	7	Sensor to be placed at the exit of blower fan. The employees are to be alerted by means of alarm.	
	Low moisture of dhool (raw material).			5	7	5	4	Moisture sensor to be provided at the exit of oxidation unit chamber. Alarm is to be triggered when moisture value of dhool falls below the recommend value.	
	Less feed of raw material to the drier chamber.			5	8	4	5	Sensor to be installed at the entrance of drier for altering the employees when dhool feed is improper.	

Note: Q-quality, M-maintenance, S-sales

Table 3 TFMEA rating of failures by maintenance department

Process name: Drying								Last update on:	
Members present:								Updated by:	
TFMEA number:								Date:	
Failure mode	*Cause of failure*	*Effects of failure*	*Present control*	*Rating*	*Departments*			*Recommended activities*	*Approved by*
					Q	*M*	*S*		
High fired tea	High inlet air temperature.	Burnt taste of tea	Manual control using thermometer	6	8	9	8	Thermocouple with digital display/sensor to be installed in the chamber.	General manager
	Cold air induction fan not working.			8	8	8	6	Andon alarm signal to be placed, when fan is not working.	
	Fluidised dryer Vibrator not working.			8	8	9	9	Andon alarm signal to be placed, when vibrator is not working.	
	Improper air velocity in the drying chamber.			8	8	9	7	Sensor to be placed at the exit of blower fan. The employees are to be alerted by means of alarm.	
	Low moisture of dhool (raw material).			5	4	7	4	Moisture sensor to be provided at the exit of oxidation unit chamber. Alarm is to be triggered when moisture value of dhool falls below the recommend value.	
	Less feed of raw material to the drier chamber.			6	3	8	5	Sensor to be installed at the entrance of drier for altering the employees when dhool feed is improper.	

Note: P-production, Q-quality, S-sales

Table 4 TFMEA rating of failures by quality control department

Process name: Drying								Last update on:	
Members present:								Updated by:	
TFMEA number:								Date:	
Failure mode	*Cause of failure*	*Effects of failure*	*Present control*	*Rating*	*Departments*			*Recommended activities*	*Approved by*
					Q	*M*	*S*		
High fired tea	High inlet air temperature.	Burnt taste of tea	Defects are identified after production is completed and the samples are sent to the tea tasters for predicting the quality of tea.	9	8	8	6	Sensors to be provided to maintain the 120ºC temperature in the first chamber of fluidised vibrator.	General manager
	Cold air induction fan not working.			8	8	6	8	Information about the status of tea intimated to appropriate departments.	
	Fluidised dryer vibrator not working.			9	8	7	8	Tea taster to collect samples at randomly and intimate about the quality of tea and emphasis necessary corrective actions if quality of tea is not meeting the standard immediately.	
	Improper air velocity in the drying chamber.			9	8	7	8	Information about the status of tea intimated to appropriate departments.	
	Low moisture of dhool (raw material).			7	4	4	5	To test the moisture by taking samples at regular interval from the raw material conveyor during production.	
	Less feed of raw material to the drier chamber.			8	3	5	6	Camera to be placed at the raw material entry to check the proper feed of dhool.	

Note: P-production, S-sales, M-marketing

Table 5 TFMEA rating of failures by sales department

Process name: Drying | Last update on:
Members present: | Updated by:
TFMEA number: | Date:

Failure mode	*Cause of failure*	*Effects of failure*	*Present control*	*Rating*	*Departments*			*Recommended activities*	*Approved by*
					Q	*M*	*S*		
High fired tea	High inlet air temperature.	Not saleable in the market.	Defects are known from the samples after checking the taste of tea by the auction people who fix the commercial value accordingly.	8	9	8	6	To create awareness to all the department employees regarding the commercial value of the XYZ's tea manufactured which is judged by quality of tea in the market.	General manager
	Cold air induction fan not working.			6	8	8	8		
	Fluidised dryer Vibrator not working.			7	9	8	8		
	Improper air velocity in the drying chamber.			7	9	8	8		
	Low moisture of dhool (raw material).			4	7	4	5		
	Less feed of raw material to the drier chamber.			5	8	3	6		

Note: Q-quality, P-production, M-marketing

5.3.5 Developing TFMEA tables for departments

The coordinator conducted the first brainstorming session to identify the primary causes of 'high fired tea' defect. Though there may be few more causes, only six important causes which lead to 'high fired tea' were considered for this study after thorough deliberation, and a TFMEA table was prepared incorporating the following important six types of failures which cause the 'high fired tea'. Improper maintenance of temperature and poor feeding of raw material (dhool) were considered as the main causes for this defect. In the same meeting, the degree of importance attached to each department regarding the occurrence of high fired tea defect was recorded. These TFMEA tables are shown in Tables 2–5. Further, the suitable ratings that indicated the cause of failure and corrective actions were listed.

Table 2 depicts the rating of failures by production department. In Table 3, the rating pertaining to the failures by maintenance department is presented. In Table 4, the rating of failures pertaining to quality control department is presented. In Table 5, the rating of failures pertaining to the sales department is presented. These rating have been designed compatibility to use 1–10 point Likert scale. As shown, the ratings of failure with respect to each department varied according to the opinion of the TFMEA members on the cause of the occurrence of high fired tea defect.

6 Process activities

The following tables were distributed to the sample executives of the four departments with a request to notify the causes of failures and to recommend the corrective actions. Table 2 shows the evaluation of the sample executives about the failures by production department. Likewise, the sample executives from the three departments namely maintenance, quality control and sales were asked to evaluate the failures in the process of 'high fired' tea. Their evaluation has been presented in Tables 3, 4 and 5.

Table 6 TFMEA Application on high inlet temperature

Course of failure	*Effects of failure*	*Departments*	*Ratings*	*Recommended activities*	*Approved by*
High inlet temperature	Burnt taste of tea	Production department (P)	7	Thermocouple with digital display to be installed in the chamber.	General manager production
		Maintenance department (M)	6	Thermocouple with sensor control unit to be installed in dryer.	General manager maintenance
		Quality control department (Q)	9	Temperature sensors to be provided to maintain 1200c temperature in the first chamber of fluidised vibrator.	General manager QC
		Sales department (S)	9	To create awareness to all the departments.	General manager sales

7 Cost benefit analysis

The main object of this study is to calculate the cost of savings in the tea manufacturing process when rectifying the failures due to high inlet temperature by applying TFMEA. After identifying the causes of occurrences of high fired tea by developing TFMEA tables, the feasibility of prevention was identified based on the recommendation for successful implementation.

As a test basis, only one cause of failure that is due to 'high inlet temperature' was taken. A brainstorming session was conducted with staff and workers of production, maintenance, quality control and sales departments by explaining the salient features of TFMEA and its process of implementation and also rectification of the above failure. Due permission was accorded by the top management of the tea factory to carry out the above process. In this case, the temperature of drying process were modernised using thermocouples for temperature detection and alarm systems were installed to prevent the occurrences of high fired tea defect.

Table 6 shows the intensity of failure due to high inlet of temperature as evaluated by the selected executives of the four departments.

Table 7 explains the process details and the cost of savings after rectification of failure due to 'high inlet temperature'.

Table 7 Savings in cost

Description	*Cost of tea/kg (INR) (A)*	*Quantity of tea wasted in dryer per month in kg (B)*	*Savings in cost© = (A*B) (INR)*	*% of saving to total cost after CTFMEA implementation (approximately cost of 19 lakhs kg/month)*
Cost of 500 kg of tea wasted during manufacturing process because of high fire occurred due to high temperature.	106	500	53,000	2.789%

Table 6 shows that the improper high inlet temperature would result in burnt taste of tea. This entirely deteriorated quality of tea. Hence, the tea may either remain unsold or auctioned for a very meager amount. It affects the company in terms of losing profit. In this regard, the process of TFMEA was implemented by involving the four related departments in the company by requesting the workforce of all departments to offer their suggestions and to recommend suitable corrective actions to get rid of the failure. The ratings obtained in ten point Likert scale also have been depicted in Table 6. If the recommendations of the four departments were carried out, then the high fired tea at drier area could be checked and maintained properly. On carrying out the recommendations, the savings in cost would be INR 53,000 per month (refer Table 7). The cost incurred before and after implementing TFMEA was compared for a particular period. This comparative study was carried out to analyse the cost benefit achievable in XYZ through the implementation of TFMEA.

8 Identifying the cost benefit of failure cost

Cost of quality is the sum of cost incurred for improving quality. The cost of quality is classified into three categories namely prevention cost, appraisal cost and failure cost (PAF model) by Feigenbaum (1991). This model is widely accepted (Moen, 1998). However, due to lack of awareness, the prevention, appraisal and external failure costs are not accounted by the management in XYZ tea industry. Therefore, while carrying out the research being reported here, only the internal failure cost was incorporated with TFMEA. It was found that in XYZ tea industry, the internal failure is one of the causes which affected the production with poor quality of tea. Therefore, the internal failure cost was considered for analysing the cost of implementing TFMEA associated with identified internal failures. This cost was considered while implementing cost-based total failure mode and effect analysis in XYZ tea industry.

The effects of the failure were identified and an appropriate cost associated with the internal failure was calculated. Here, the internal failure cost was considered in order to calculate severity cost value of tea industry. The structure for calculating internal failure cost given by Wang (2008) was taken as base. According to Chin (2009), internal failure cost = rework cost + reprocessing cost + downgrading cost + waste disposal cost + overtime cost + opportunity cost + excess inventory holding cost.

Wang's calculation is more common which is applicable to general manufacturing industries. However, Wang's formula could not be suitable and applicable to XYZ tea industry because the tea industry has some unique mode of processing. Hence, the same calculation given in Chin (2009) could not be applied for calculating total internal failure cost in tea manufacturing. This is due to the reason that some of the cost components proposed by Chin (2009) were neither in practice nor available in XYZ.

There is no wasting of tea leaves in XYZ tea industry because those tea leaves left over as waste are again reprocessed. In this tea industry, the management allots a sum to improve the potentiality of the machines and to upgrade the technology which is considered as opportunity cost in this industry. As soon as tea is produced, the whole products are transported to a central warehouse where the price of the tea is determined according to its quality and the amount is paid. Therefore, the excess inventory holding cost does not arise in XYZ tea industry. In this background, the following equation was used.

$$\textit{Internal failure cost}\ (IFC) = \textit{Opportunity cost} + \textit{Reprocessing cost} + \textit{Overtime cost}.$$

The various cost elements involved in the manufactured tea is tabulated in Table 8. In the first instance, the cost data before implementation of TFMEA was obtained. Then, the various cost data were gathered from the management of the tea industry after taking corrective actions as suggested by TFMEA team. The cost accounting before and after carrying out the CTFMEA was carried out and is shown in Table 8.

Due to the implementation of TFMEA, direct costs and indirect expenses were considerably reduced making savings in their respective heads. However, the factory up-keep cost was found to increase by 0.50 INR per kilogram. This may be due to the wear and tear of machines and for spending to upgrade the technology. The failure cost was found reduced by 0.13 INR per kilogram. Altogether, the saving in the production

cost was calculated to be in Indian national rupees (INR) as INR 4.00 (110–106) per kilogram after the implementation of TFMEA.

The production cost per year to manufacture one kilogram of tea was found to be INR 110 per kilogram before the implementation of TFMEA. According to the opinion of managers of various departments and after personal observation in XYZ tea industry, the internal failure cost during manufacturing was estimated to be around 70 million INR per year on production of 22 millions of kilogram of tea. Internal failure causes the deterioration of quality in tea and loss of production time. This downtime was considered as a major internal failure cost. Based on the results of implementing TFMEA, the failure cost was reduced and production rate was increased which ultimately resulted in reduction of the production cost of tea as well as increase in output rate resulting the increasing of the marginal saving during the production of tea in XYZ tea industry. Thus the savings would be:

Product *c*ost (before the implementation of TFMEA = INR 100 per kilogram

Product cost (after the implementation of TFMEA = INR 106 per kilogram

The savings in the production cost = INR 4 per kilogram (whereas the actual cost kept constant at INR 242 per kilogram). Therefore the saving in the production cost is INR 4 per kilogram as shown in Table 8.

Table 8 Cost calculation in XYZ tea industry before and after CTFMEA implementation

Description of cost components		*Before*	*After*	
		Production cost per kilogram of tea before CTFMEA (INR)	*Production cost per kilogram of tea after CTFMEA (INR)*	*Savings in INR*
Direct cost	Direct labour cost	80.00	76.54	3.46
	Direct material cost			
	Direct expenses			
Indirect expenses	Fuel cost	5.00	4.57	0.43
	Labour cost	5.00	4.57	0.43
	Electricity cost	7.50	6.95	0.55
Factory expenses	Factory upkeep	1.00	1.50	–0.50
	Failure cost	*0.30*	*0.17*	*0.13*
	Tax	0.50	0.50	-
Administrative expenses		4.00	4.00	-
Office rent and employee welfare		5.00	5.00	-
Selling expenses	Brand marketing	1.20	1.20	-
Profit		0.50	1.00	0.50
Total		110	106	4

9 Decision making on the results

The coordinator submitted to the management the details of cost analysis before and after the implementation of TFMEA. The top management approved and agreed to implement the recommended actions. The coordinator conducted a meeting with top management and other employees to initiate the TFMEA implementation process in a full-fledged manner. The top management continuously monitored the performance of respective TFMEA team to solve the quality failures in the process of tea manufacturing. Failure occurs during the production and affects the cost of tea. Since tea shoots are perishable they cannot be used beyond 12 hours. Therefore, TFMEA approach will be more suitable and effective for a time bound manufacturing process to overcome all possible failures.

In Table 9, the internal failure cost before and after implementation of TFMEA found in XYZ is shown. The total revenue generated in a year before and after TFMEA has been presented in Table 10 along with the savings in a year gained in the production of tea.

A total of 22 lakhs kilogram of tea in a year was produced before the implementation of TFMEA. During this process, the production cost per kilogram of tea was INR 110. After the implementation of TFMEA, the rate of production has considerably increased to 2.3 million kilogram in a year. At the same time, the production cost of tea has decreased to INR 106 per kilogram. Therefore, the cost benefit of producing the tea in the XYZ factory in a year would be INR 180 millions of INR after the implementation of TFMEA.

Table 9 Calculation of internal failure cost before and After CTFMEA approach

Status in XYZ industry	*Opportunity cost lakhs of INR (A)*	*Reprocessing cost lakhs of INR (B)*	*Over time cost lakhs of INR (C)*	*Internal failure cost/year lakhs of INR(A + B + C)*
Before CTFMEA	30	20	30	80
After CTFMEA	20	5	15	40

Table 10 Production cost of tea before and after CTFMEA implementation

Status in XYZ	*Annual production of tea (kilogram)*	*The production cost of tea per kilogram (INR)*	*Total revenue generated per year*
(Crore of INR)			
Before CTFMEA	220,00,000	110	242.00
After CTFMEA	230,00,000	106	243.80
The amount saved per year			1.80

10 Ensure the organisation's vision and policy on TFMEA implementation

Based on the above results, it was ensured that the management's vision and policy towards reducing the failures occurring in tea manufacturing were effectively controlled through the implementation of TFMEA technique. This helped the manufacturer to maintain its sustainability and to achieve competitive advantage.

11 Discussions and conclusions

Majority of the tea producing countries are located in the continent of Asia. Among them China, India and Sri Lanka are the major producers of tea. Tea continues to be the most popular drink in the world. As there is a steady increase in demand for tea, the manufacturers are looking for improving the productivity of tea with enhanced quality to face the severe competition from other tea growing countries. However, it is little known that tea manufacturing is largely influenced through engineering practices. Hence, the role of engineers is significant in improving the quality of tea (Temple et al., 2000).

All employees associated with tea manufacturing can participate in TFMEA implementation for enhancing quality of tea by reducing the failures. The implementation of TFMEA aided the management of XYZ to increase the production rate and subsequently minimise the manufacturing cost and process time due to the reduction of internal failures. Ultimately, when the internal failures are reduced using the appropriate quality improvement technique like TFMEA, the production cost of tea is considerably reduced and the volume of production is largely increased, resulting in quality improvement. This research was undertaken in XYZ considering one failure namely 'high fired tea' and its cost benefit factor on the implementation of TFMEA. There are many other failures in tea manufacturing which may be overcome by implementing same technique. The unique contribution of this study is that TFMEA technique can be applied in cost benefit mode. Since all the departments are involved in evaluating the failures occurring in one department, it could easily be detected and its effect also could easily be estimated through application of TFMEA technique. Further, it reduced the processing time and the production cost and helped in continuous improvement of quality. The aim of this research is to maintain flawless manufacturing process to improve the performance by reducing the cost and time in tea production and to improve and sustain the quality of tea. The outcome of the analysis clearly indicated a profit of 1.80 Crores of INR after rectifying one type of internal failure. Many of the costing techniques like life cycle-based costing, and activity-based costing may be applied to initiate researchers carrying out cost-benefit analysis by implementing CTFMEA technique to reduce the failure cost in the production of tea.

12 Limitations

The following aspects formed the limitations of the research presented in this paper.

1 Tea production rate is assumed to be constant throughout the year for consideration of cost.

2 There were failures due to many factors. The scope of this research was confined only to the failure and its cost benefit analysis that occurs due to high fired tea.

3 The ratings of the causes of failures were obtained from employees of four departments through verbal discussion which may not be accurate.

13 Implications

The implementation of TFMEA approach under real-time scenario is a maiden attempt and will assist the tea manufacturing companies to improve the quality of tea by overcoming the failures systematically and help the manufacturers to gain significant profit with the existing input. This will also help the companies to establish its brand image in the market among the competitors and to accomplish the vision of the management.

13.1 Practical implications

The TFMEA implementation process involves all level employees of the tea industry especially the engineers and the management. This may create a motivation among participating team and the management to give competition to the fellow competitors nationally and internationally. Besides earning profit by the company, an important economic effect is helping nation to earn more money through foreign exchange by successful participation in the international tea trade. A flawless manufacturing process increases the performance of the company thus makes a huge profit.

13.2 Theoretical implication

So far, cost and benefit factor analysis has been done on application of FMEA. Since no study is available on CTFMEA, the present study is one more source adding to a literature on TFMEA. Further, it helps proposing a new model called CTFMEA.

14 Scope for further research

This paper was undertaken in XYZ Tea Company considering the one failure namely 'high fired tea' during drying process and its cost benefit factor on the implementation of TFMEA. There are many other failures in tea manufacturing which may be overcome by implementing same technique. The study can be extended to evaluate failures in other important processes in tea industry and also in other manufacturing industries. CTFMEA can be employed in all manufacturing industries to evaluate the cost benefit factor. However, this study was confined to evaluate failure modes of selected nine failure modes in drying process of tea industry. This study can be extended to incorporate all the manufacturing process in all the manufacturing industries. A comparative CTFMEA study can be conducted taking two or more similar industries in one geographical area. The same study can also be extended taking few manufacturing industries by comparing Indian manufacturing industries with the manufacturing industries abroad.

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