Journal of Science, Technology, and Humanities : July - December 2003, Vol. 1, No. 2, pp. 165-173.

REDUCTION OF PRODUCTION LOSS IN PRODUCTION PROCESS BY USING FAILURE MODES/EFFECTS ANALYSIS (FMEA) TECHNIQUE

Aroon Buathong* and Anek Singhakowinta

Engineering Management Program, Faculty of Engineering, Burapha University, Bangsaen, Chonburi 20131, Thailand.

Received September 2003; accepted November 2003.

ABSTRACT

Failure Modes/Effects Analysis (FMEA) is one of various methods applied in Design for Manufacturing (DFM) methodology of concurrent engineering used to effectively reduce product loss in production process. FMEA has provided a disciplined technique to identify and help eliminate potential concerns in design and processes. Responsibility for the preparation of a FMEA rests on specific individuals; however, FMEA input should be a team effort. In this case study, FMEA was used as the tool to find out root causes of failure in carbon black production process. Three categories of root causes of failure were made, based on FMEA criteria called "RPN (risk priority number) score", the higher RPN score representing worse situation. The outcome of this case study was cost saving. Each category provided a certain amount of cost saving after FMEA was implemented. The defect rates were reduced from 46.70% to 27.41% in the first group, 14.54% to 9.71% in the second group, and 6.35% to 3.45% in the third group. Cost saving anticipated from this case study was approximately 11,200,000 Bahts/year or 27% of total loss in year 2000.

Keywords : FMEA, failure modes, improvement, concurrent engineer, reliability, critical, RPN.

INTRODUCTION

Competition is high in business today, when global economy is seeing country and regional boundaries falling apart. To survive and to prosper required people in business to be active and progressive all time, we should improve their ways of work and reducing expenses. Such efforts and measures are required and intensified by the economic crisis sweeping Asia at the moment. ABC, a carbon black plant, is no exception to the rule, as it has to keep itself at the tip of technology

* Corresponding author. E-mail address: aroon.buathong@gesm.ge.com

edge and, at the same time, be competitive in overall Asian environment. ABC is faced with tough competition, which can get tougher, and the largest problem is seen in the loss of productivity. The solution, therefore, could be a large factor to contribute to the survival and even to business gain. Many techniques have been used in order to improve the efficiency and the efficacy of the plant. Some have been successful to certain degree, while others have failed. When a plant cannot improve its productivity, while others do so, a number of things happen relatively:

1. higher operating cost,
2. inability to sustain production plan,
3. inadequate stock of products for supply to customer,
4. unstable qualities of products, and
5. loss of customer base and confidence.

There are many tools/methods that can be used to solve the problems. The most familiar tools widely used is Concurrent Engineering (CE), which is also known by other names, including simultaneous engineering, concurrent design, life-cycle engineering, integrated product development, and team design. CE is a dramatic departure from the past tools in use, and, at the same time, it is a new design for the present environment and technology, requiring extensive disciplinary co-operation and integration of such fields like design engineering, manufacturing and material management.

All production processes are likely to fail, subject to, among other things, the quality of raw materials, the technology, the process details, including the set points, the cut points, the sampling and testing methods and frequency, the supervision work, and the maintenance done. To improve on yield, efficiency and productivity, and FMEA have been successfully used (Stamatis, 1994; Dhillon, 1985). The general procedures for conducting a FMEA, describing the major process improvement in process start-up, including brainstorming, FMEA, and design of experiments (DOE) are well-known (Beauregard et al., 1992). For quality deployment system, especially in the design and development phase, FMEA and FMECA (Failure Modes/Effects and Critical Analysis) have been effective tools for failure prevention and for quality control process chart (Shigeru and Akao, 1994). A quantitative identification of problems is well illustrated by using FMEA and FMECA for the travelling sprinkler analysis (Juran and Gryna, 1993). FMEA is also demonstrated in identifying elements giving rise to fright in the early use of radar for aircraft (Kolarik, 1995). Even the use of FMEA was found useful in solving failures of integrated circuits problems (Halpern, 1979). FMEA has been used in conjunction with the statistic methods for setting the optimization tolerance in assembly stacks and setting of realistic capability target of the account. The application of the method is also illustrated using a case study from the automotive industry through the use of interactive software and has also been used in conjunction with re-engineering tool (Swift, 1999). FMEA have been used in the support of DART (Design Analysis Re-engineering Tool), together with a state-of-the-art relational database and standardized data format, to permit long-term management of plant safety related information. The plant design is reviewed in a step-by-step logical fashion by constructing fault trees that identify the link between undesired consequences and their causes (Billington et al., 1999). FMEA has been successfully supplemented with other tools, like the computerized "expert system." Organization of a stimulation subsystem, which is a component of a comprehensive expert system for FMEA, is well presented (Liu and Yang, 1999; Russomanno, 1999), wherein the capability is shown for incorporating computer-aided analysis and design tools early on into the conceptual design of an engineering system before any commitment.

For other qualitative applications, FMEA is used as the tool for qualitative circuit model failure analysis (Lee, 1999). On simulation aspect, FMEA is used in simulating complex behavior of electrical devices for automotive electrical and electronic system, (Snooke, 1999.). Finally, FMEA has been shown to be an invaluable tool for problem-solving in regard to planning measurement and for the final analysis of finished product performance to meet a zero reject capability in industrial paint and powder coating plant (Cowley, 1999).

Preliminary investigations in our case have revealed that production problems were largely related to production failures and inadequacies. Hence, to improve the performance of ABC production, we proposed to use tool called Failure Modes/Effects Analysis (FMEA) to solve the problems in the first place. The purpose of the case study is following:

1. to recommend the company to reduce production loss by using FMEA methodology,
2. to decrease product loss and increase cost saving,
3. to adapt FMEA methodology for the failure prevention,
4. to improve and maintain customer satisfaction, and
5. to improve profitability for ABC by lowering production cost.

METHODS

ABC has never used FMEA tool in problem solving. On the other hand, ABC is accredited with ISO9002, and uses the corrective and preventive actions from the ISO9002 system. However, the corrective and preventive actions are after-the-event actions only, and are relevant only for those events. The potential and critical functions are not included if they do not initiate the problems in the first place and thus caused these production loss of that time. Hence, sometimes the same problems recur within a short period of time. In order to improve the production efficiency by eliminating the causes of failures that give rise to production loss, FMEA and its highly efficient methods and tools are used to solve the problems. Therefore, the steps of active prevention of production loss start from data collection, preparation and compilation of production loss in the last three years. It is necessary to understand the production process in order to identify the critical functions during the process. Prior to evaluating and eliminating the causes of problems, this exercise has to be treated as a project, with an agreement from the top management and the project proposal has to be prepared and approval obtained from the top management. This is because of the requirement of FMEA involving a team function. Therefore, a project team is formed, comprising technical advisor, process shift supervisor, senior maintenance, safety supervisor and quality control supervisor. Besides the team, budget should be available to support the teamwork. A schedule for the work of the team is also required as to how long they will achieve the various steps and finally the goal, that is, to eliminate the root causes of problems; after which, benefits must be established after achieving the target by using FMEA technique.

Before evaluating the causes of the problems we should establish the standard criteria: severity of the failure (S_R), frequency of the failure (F_R), and the detection rate of the failure (D_R). The team needs to consider the criteria separately; first, there is the severity: the team should consider the severity compared with the objective evidence. Then, the next step is to set the explanation of each criterion by using the following equation:

$$\text{Risk} = (S_R) \times (F_R) \times (D_R)$$

The major components of the process based on the area code are identified and use the fishbone diagram to find out the sub-functions of the major components. Regarding the identification of the major components and sub-functions of major components, there are a lot of main causes of failures. It is quite difficult to evaluate and eliminate all those causes in the limited time. Therefore, the risk priority number (RPN) result is used as a decision factor to classify the causes of failure into a small groups as shown in Table 1.

the FMEA technique so that the action plan will be set up in order to eliminate the cause of failure and prevent the problem from recurring. In order to make it easy in proposing or attaching the causes of failures, the action plan should be classified into 4M. The 4M means "Man, Machine, Material, and Method". The causes of failures should be classified into the groups of 4M. Classifying the causes of failures into 4M groups help to clarify the causes of failures and make it easier to prepare the essential provision for 4M.

Table 1. Classification criteria.

Group	Severity	Frequency	Detection	Opportunity of problem solving
First group	High-very high	High-very high	Low-very low-absolute certainty of Non-detection	Very high-high
Second group	Moderate	Moderate	Moderate	Moderate
Third group	Minor-low	Remote-very low-low	High-very high	Low-very low

Thus, the first group will be the group for first priority in problem solving by using FMEA technique due to high risk and high impact.

The second group will be the next one to be evaluated and improved. The last group has rather low risk but it does not mean that it is unnecessary for it to be improved. If improvement is needed, there is no immediate necessity as for the first group.

After collecting the data and after understanding the production process and the evaluation criteria of FMEA technique, the next step is a design and development of FMEA phase for failure prevention by using the typical FMEA form. The cause of failure is identified after development of

RESULTS

Only critical root causes of failure are appraised by using RPN score as a factor for the resolution. The RPN score is the product of the multiplication of three criteria of FMEA. The lowest value of each criterion represents the third priority, the next value represents the second priority, and the highest value represents the first priority. Therefore, Table 2 is the classification criteria using for ranking the priority of the work in this case study.

Table 2. Classification criteria (RPN score).

Priority for work	RPN score
Third	1-36
Second	37-216
First	217-1000

The highest score represents the worst situation. In criteria setting, the major failure mode is identified.

From the critical function, it amounts to 46% of product loss in year 2000. Therefore, it is necessary to resolve the problems and suggest failure prevention due to high risk and high impact. After the action plan is taken, the RPN is expected to be reduced by at least one step.

In order to increase the efficiency of the action plan, the particular objective relevant to the action plan should be clarified. Generally the particular objectives are Man, Machine, Material, and Method or in other word "4M".

When the relation between the action plan and 4M is brought out, it follows to realize the essential provision system for 4M. The essential provision system will contribute to the accomplishment of action plan through 4M. Some systems need to be set up while some systems need training courses. Table 3 shows the essential provision system for 4M.

Table 3. The essential provision system for 4M.

4M	Essential provision system	Responsibility
Man	: Training course • In house • Outside	: Human resources section : Operation sections
Machine	: Performance of the equipment : Full capacity : Operating manual : Preventive maintenance plan	: Operation sections : Maintenance section
Material	: Specification : Cost	: Operation sections : Purchasing section
Method	: Procedure & work instruction	: Operation sections

When the product loss is improved after process FMEA is implemented, the outcome in terms of business is cost saving.

Table 4. Anticipated cost saving.

		First group	Second group	Third group	Total	Cost (Bahts)
Product loss in 2000	(Ton)	968.29	301.5	131.80	1401.50	28,030,000.00
	(%)	46.70	14.54	6.35	67.59	
FMEA was implemented						
Expectation product loss	(Ton)	568.00	201.45	71.76	841.26	16,825,200.00
	(%)	27.41	9.71	3.45	40.57	
Cost saving	(Ton)	400.00	100	60	560	11,200,000.00
	(%)	19.29	4.83	2.9	27.02	

DISCUSSION

Due to the efficacy of FMEA used, root causes of failure have been identified and eliminated. As the outcome of the process improvement is the cost saving, the amount of cost saving is evaluated. The first group gives high impact to production process as it consists of critical functions. Therefore, the anticipated cost saving is a large amount, approximately 8,000,000 Bahts per year or 19% of cost saving.

The second group gives lower impact than the first group, but it consists of many functions of possible failures with high frequency of occurrence. Cost saving for the second group is approximately 2,000,000 Bahts per year or 5% of cost saving.

The third group gives the lowest impact to production and always consists of non-critical function with low frequency of failure. Therefore, cost saving expectation is much less than other- about 1,200,000 Bahts per year or 3% of cost saving. Thus, the total product loss that is saved in those three groups after root causes of failure were eliminated is approximately 27% or in other words 11,200,000 Bahts per year compared to year 2000.

CONCLUSION

Using the FMEA methodology as a tool to identify and eliminate root causes of failure has been discussed. For this case study, product loss is reduced from 67% to 40.57% or 27% of cost saving, compared to the year 2000. FMEA is proven to be a powerful tool for finding out the root causes of failure, offering the recommendations for action plans for corrective and preventive measures. The analysis has shown the critical root causes of failure. When RPN score in the FMEA work sheet decreases, it indicates improvement, which means of the product loss in the process. FMEA also gives recommendation for second and third priorities for problem solving, just as for the first priority.

FMEA has been adapted for the failure prevention, resulting in decreased product loss, increasing cost saving. Customer satisfaction is also maintained and improved since the plant now has high reliability, with small amount of product loss; therefore, the stock of product is sufficient to satisfactorily meet customer needs on time. The indicator of the customer satisfaction is customer complaint. The number of customer complaints is expected to reduce. However, customer complaint can be due to several causes, such as packaging, quality, and delivery. Therefore, if FMEA is applied to all processes including quality assurance, all causes of customer complaints mentioned above would be reduced.

FMEA has been used in other Thai industries, particularly in the tyre manufacturing industry (Buabucha,1998). FMEA is used as a tool to study and analyze factors affecting compound quality problem during the mixing process. It also uses FMEA to develop the appropriate process quality assurance in the factory. In our case, FMEA is used for the first time, and satisfactorily, in the carbon black industry. There are similarities between the tyre manufacturing industry and carbon black industry. In both cases, FMEA has been used as the tools for studying, analyzing and preventing the product non-conformance achieving similar objectives. Finally, the result of both case studies is the reduction of product loss. The carbon black process and the tyre manufacturing process continue one to the other. Carbon, which is produced as the product in the carbon black process, is used as the major raw material for tyre manufacturing. Therefore, both studies together lead to improved processes and process improvement high level of reliability.

As FMEA is meant to be a 'before-the-event' action rather than an 'after-the-event' action, it is appropriate to use FMEA when (1) new systems, products or processes are being designed; (2) existing designs or processes are being changed, to look at the risk of change; (3) carry-over designs/ processes will be used in new applications or new environments.

Furthermore, FMEA can be developed for use with quality control or quality assurance planning or even in investigation of customer complaint.

FMEA for quality control and quality assurance planning

Product verification needs to be developed, reviewed and updated. FMEA is useful when developing, reviewing and updating pre-qualification control plan and inspection acceptance criteria include in the work instruction.

FMEA for investigation of customer complaint

Customer complaint needs to be carried out for problem-solving as soon as possible, to avoid recurrence. FMEA contributes to finding out the root causes of failure and the failure prevention aims at increasing customer satisfaction.

There are several engineering approaches included in FMEA. Problem prevention provides the foundation with keys linked to problem-solving and customer focus. Hence, FMEA has linkages to problem-solving activities, reliability, and process control methods. The result from problem-solving activities becomes input to FMEA, and the result from FMEA provides input to reliability analysis. The results from FMEA eliminate or reduce the occurrence of product/process failures and; therefore, act as prevention tool in process control methods to control, before certain undesirable events occur within the process.

In the long run, FMEA can be developed from the work sheet in personal computers as the "expert system". By collecting data (history of root causes of failure, recommendation, and action plan) as the database for the system. Furthermore, continuous development can be performed to enable high performance in the future.

RECOMMENDATION

To be successfully implemented FMEA, the followings are followed:

1. the company must have complete data collection in every process to enable determining the root causes of failures;
2. the company should realize the advantages of FMEA technique to identify the root causes of problems;
3. the management should support the technique;
4. the production staff should not allow the engineers to solve few problems based on their experiences, and the engineers should not find out the root causes of the problems by using DOE step by step; and
5. the production staff should update their skills, and use modern techniques to improve their work.

REFERENCES

Beauregard, M.R., Mikulak, R.J., and Olson, B.A. 1992. *A Practical Guide to Statistical Quality Improvement Opening up the Statistical Toolbox*. Van Reinhold, New York, pp. 1-89.

Billington, A., Blondiaux, P., Boucau, J., Cantineau, B., and Mared, A. 1999. The Design analysis re-engineering tool-for design basis justification and safety related information management. *Nuclear Engineering and Design* 192 (2-3):295-302.

Buabucha, S. 1998. Process Quality Assurance Development for Compound Mixing in the Tyre Manufacturing Industry. Master Degree Thesis in Engineering,. Department of Industrial Engineering, Graduate School, Chulalongkorn University, Bangkok, Thailand, pp. 91-128.

Cleetus, J. 1992. *Definition of Concurrent Engineering*. Concurrent Engineering Research Center. Morgantown, West Verginia.

Cowley, M. 1999. The control of quality in industrial paint and powder coating plant. *Transactions of the Institute of Metal Finishing* 77 (part 3):46-49.

Dhillon, B.S. 1994. *Quality Control, Reliability, and Engineering Design*. Marcel Dekker, Inc., New York, pp. 145-169.

Halpern, S. 1979. *The Assurance Science and Introduction to Quality Control and Reliability*. Prentice-Hall of India Private Limited, New Delhi, pp. 90-261.

Juran, J. M. and Gryna, F. M. 1993. *Quality Planning and Analysis*. Tat. McGraw-Hill Publishing Company Limited, New York, pp. 40-78, 260-274, 531-546.

Kolarik, W.J. 1995. *Creating Quality Concept, System, Strategies and tools*. McGraw-Hill, Inc., New York, pp. 242-287.

Lee, M.H. 1999. Qualitative circuit models in failure analysis reasoning. *Artificial Intelligence* 111 (1-2):239-276.

Lui, T. l. and Yang, X.M. 1999. Design for quality and reliability using expert system and computer spreadsheet. *Journal of the Franklin Institute* 336(7):1063-1074.

Russomanno, D. J. 1999. A function-centered framework for reasoning about system failure at multiple levels of abstraction. *Expert systems* 16 (3):148-169.

Shigeru, M. and Akao, Y. 1994. *Quality Function Deployment*. Productivity Press, Cambridge, MA, pp. 4-28.

Snooke, N. A. 1999. Simulating electrical devices with complex behavior. *All Communications* 12 (1-2):45-59.

Stamatis, D.H. 1994. *Failure Mode and Effective Analysis FMEA from Theory to Execution.* ASQC Quality Press, Milwaukee, Wisconsin.

Swift, K.G., Raines, M., and Booker, J.D. 1999. Tolerance optimization in assembly stacks based on capable design. Proceedings of the Institution of Mechanical Engineers Part-B-*Journal of Engineering manufacture* 213 (7):677-693.