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Quality Improvement Strategies Using Failure Mode and Effect Analysis (FMEA): A Case Study in a Bottled Mineral Drinking Water Company

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Abstract: The purpose of the case study is to help a company improving quality control in their “bottled mineral drinking water” production process. By analyzing factors contributing to the defects during production process, defects on end products can then be minimized. Few methods are used in the study, e.g.: Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA). SPC is used to measure and control product quality to fit with the specified standards. FMEA is used to identify failure mode and how to prevent their re-occurrences. By using SPC and FMEA, some recommendations are made to help company minimize their product defects.

Key words: Strategy, quality control, statistical processing control, failure mode and effect analysis, reoccurrences

INTRODUCTION

A more competitive environment now a days requires firms to strengthen their professionalism in managing their business operation. One way to do, it is by making sure its product quality, so productivity and performance can be enhanced. Statistics from BPS shown that the growth of manufacturing industry for small and medium enterprise in Indonesia in 1st quarter of 2013 has increased by 4.84% vs. the same quarter in 2012. On the other hand, the growth in mineral drinking water segment shown an increase of 9.41% (BPS, 2014). BPS also shown which provinces have an increase of >2% in 1st quarter 2013 vs. 4th quarter 2012 for small and middle enterprise manufacturing industry segments.

Many firms in Indonesia have adopted quality control management system in their operations. Examples in mineral drinking water industry are by producing the mineral drinking water as per quality set by the National Quality Standard (SNI). It is expected that firms adopting SNI standard can maintain and increase the quality of their products which in turn can help in maintaining its competitiveness in the global market.

Quality control is usually used in making sure the end products of a firm is in accordance to an agreed quality standard and any defects during production if any can be rectified and not reoccur in the future. In reality, however, many products in the market still have defects beyond acceptable defect norm set by the company. Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA) Methods are therefore can be used for a better quality control application of the firm. This approach aims to help firms in reducing the defect occurs in the production process flow.

Literature review: Quality is one of the key drivers influencing consumer decision in purchasing product or service. Products or service with a good quality record can increase consumer loyalty (Mohan *et al*., 2012). Quality dimensions consist of performance, durability, conformance, perceived quality, features, aesthetics, reliability and serviceability (Montgomery, 2009).

Failure Modes and Effects Analysis (FMEA) is an engineering technique used to define, identify and eliminate known and potential failures, problems and errors from system, design, process or service before they reach the client (Chin *et al*., 2009). The FMEA technique has gained wide acceptance and applications in a wide range of industries such as aerospace, nuclear, chemical, manufacturing, nursing and medicine (Guimaraes and Lapa, 2004; Duwe *et al*., 2005; Paparella, 2007; Yang *et al*., 2011).

FMEA is a systematic activity in identifying and evaluating potential failure mode of a system, a product or a process, especially by analyzing root function of a product or process or factors influencing those products or process (Pande *et al*., 2002). A failure mode is anything that is considered as defect or failure in design against the set specifications or changes in product that cause a disturbance in the product function. By eliminating failure mode, FMEA can increase product or service capability which at the end enhances customer satisfaction. FMEA

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can be applied in any fields both in manufacturing as well as in service of all kind of products. However, the application of FMEA will be more effective in a new products or process. FMEA is also effective in new product within a current process undergoing a major design changes which may influence quality of the product or process. FMEA is a systematic method which is applied because of the following reasons (Wirth *et al*., 1996):

- To identify and prioritize potential failure modes in a system, product, process or service
- To define and run measures in order to eliminate or reduce the incidence of potential failure modes
- To record analysis results in order to provide a comprehensive reference for solving future issues and problems

Previous studies done by Young *et al*. (2007) shown that SPC helped in reducing variation in the wood thickness which contributes to company's financial performance. From the data, implementing SPC by a firm is estimated to contribute a cost saving around $128,999-752,000. Fakoya (2014) in his research about failure modes and effect analysis of repeating accounting students in South African University using a deductive analysis approach that utilizes the FMEA tool to analyse the results of an in-depth interview, the analysis showed that the failure pattern were significantly similar, significantly more reliable and significantly more discernible on the risk of the repeated failures. Research and application of FMEA in industry, particularly in mineral drinking water industry is very limited. This study is therefore, aims to contribute in researching company's strategy in enhancing their product quality.

MATERIALS AND METHODS

This study is a descriptive research. Data collection method used in the study was gathered by interviews and direct observation in the company. Observations were done both in the production process as well as in the quality control activities of the company. The 5 tools were used as analysis techniques in identifying number of defects in the Bottled Mineral Drinking Water (BMDW). Control chart was used to calculate upper and lower limits control of the product. Pareto diagram was used to analyze major defect contributor for the BMDW products. Fish bone diagram was used to analyze factors influencing defect of the BMDW products. In order to determine the application of Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA) in the company, a revised control chart was used.

RESULTS AND DISCUSSION

Defect in bottled mineral drinking water can be classified into 4, i.e:

- Water defect: dirty of shortage of volume
- Lid defect: cut lid, non aligned lid, loose lid, burnt lid, leaking lid and bad or broken lid
- Cup defect: leakage cup, thin cup and bad cup
- BMDW defect: sticky, fall, exposed to oil, squeezed, broken

Defect data by category from May-July 2014 is shown in Table 1. From the above data, a Pareto diagram by defect type is shown in Fig. 1. Pareto diagram during period of May-July 2014 shown that the biggest defect type was from BMDW defect which consist of sticky, fallen, oily, squeezed and broken with quantity 12.825 pcs or contributes to 44.03%. The second biggest defect was lid defect with 7.170 pcs of occurrence or 24.62%. Next was water defect contributing 4.630 pcs or equivalent to 15.90%. The least occurrence was cup defect: 4.501 pcs or 15.45%.

Scattered diagram: Scattered diagram was used to determine the relationship between 2 variables, i.e., number of BMDW defect vs. total number of defect during the observed period. The objective was to determine whether relationship exists between the two, i.e., whether there is positive correlation, negative correlation or no correlation at all. The scattered diagram is shown in Fig. 2.

From the scattered diagram, it can be concluded that there was a positive relationship between the 2 variables. There was correlation between big numbers of X variable with big numbers of Y variable as well as small numbers of

Table 1: Defect data of BMDW May-July 2014

Defect type	No. of defect
BMDW	12.825
Lid	7.170
Water	4.630
Cup	4.501
Total	29.126

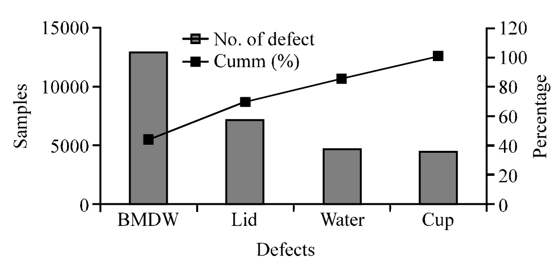

Fig. 1: Pareto diagram of BMDW defect May-July 2014

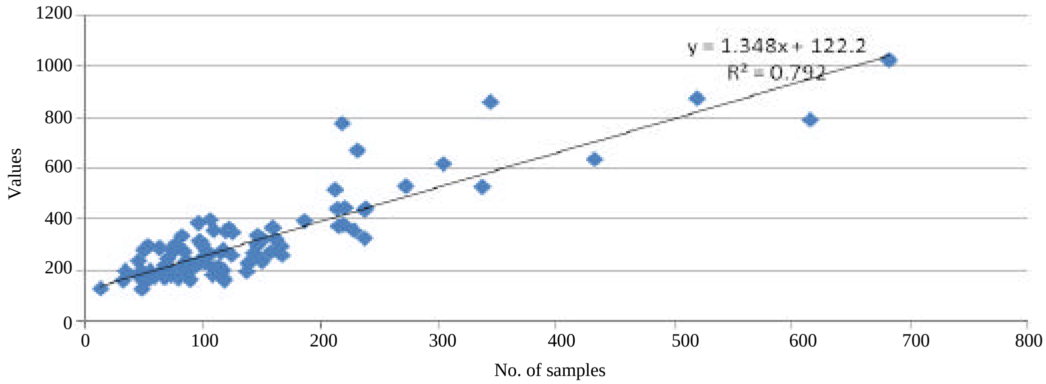

Fig. 2: Scattered diagram number of BMDW defect vs. total defect May-July 2014

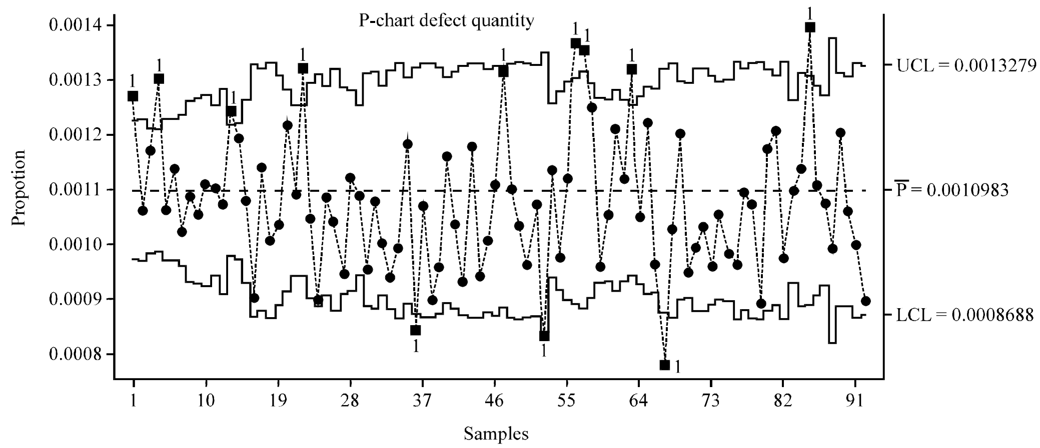

Fig. 3: P-chart for BMDW May-July 2014

X variable vs. small numbers of Y variable. Positive relationship was also indicated by a sloped trend line of the scattered diagram.

Control chart: Analysis was done using data of production quantity and number of defect for bottled mineral drinking water for the period of May 2014. Based X on data during the observed period, a p-control chart can be drawn by calculating the defect proportion, CL (Centre Line), UCL (Upper Control Limit) and LCL (Lower Control Limit) using the following steps. Defect proportion is calculated with the following equation:

$$p = \frac{\text{No. of defect}}{\text{Production quantity}}$$

UCL is calculated with following equation:

$$UCL = \bar{p} + 3\ Sp,\ UCL = \bar{p} + 3\ \frac{\sqrt{\bar{p}\ (1\text{-}\bar{p})}}{N}$$

LCL is calculated with following equation:

$$LCL = \bar{p} - 3\ Sp,\ LCL = \bar{p} - 3\ \frac{\sqrt{\bar{p}\ (1\text{-}\bar{p})}}{N}$$

After calculating the above parameters, a p-control chart for the bottled mineral drinking water from period of May-July 2014 were drawn as shown in Fig. 3. From the p-chart, it can be seen during the observation period, some data were out of norms, i.e., 12 data are above the UCL and 9 data are below the LCL.

Fishbone diagram: Fish bone diagram is a root cause analysis tool. Fishbone tools helps in elaborating all the possible cause of a problem at hand.

From the previous Pareto chart defect on production process can be classified into 4 groups, namely: water defect, lid defect, cup defect and BMDW defect. From those 4 groups there are 5 main factors influencing the product defect, namely: man, machine, material, methods and working environment.

Machine: Machine age and irregular maintenance schedule are one of the influencing factors. Age and

Table 2: FMEA summary by defect type (Data Analysis 2014)

CTQ defect	Potential failure mode	Potential effect of failure	Current control	S	O	D	RPN	Recommended action
Potential failure mode and analysis								
Water	Dirty cup or lid	Dirty water	Employee	7	3	5	105	Proper employee monitoring during process
	Water filter was not change regularly	Non sterilized water	warning	6	4	4	96	Make standard and regular schedule for changing water filter
Lid	Improper selection of lid supplier	Bad quality of plastic lid (too thin or bad)	Employee warning	6	4	3	72	Quality control and monitoring on supplier to maintain plastic lid quality
	Need to calibrate the pressing machine	Lid was not stick properly to cup		6	4	4	96	Regular control and monitoring at pressing machine
	calibration on lid cutting machine	Lid cutting process was not perfect (not aligned/straight)		7	4	4	112	Regular control and monitoring at cutting machine
Cup	Calibration roll sheet cutter on cup machine	Bad or leaking cup	Employee warning	6	4	4	96	Regular control and monitoring on cup machine
	Lack of operator knowledge in setting the correct temperature during cup making	Bad or thin cup		7	5	4	140	Make SOP or work procedure on how to operate machine properly to operators
	careless checking on produced cups	Defect cup still go to the next production process		5	4	4	80	Train operators on proper quality checking for produced cups
BMDW	Calibration on BMDW machine	Out of specs BMDW	Employee warning	6	4	4	96	Regular control and monitoring on final BMDW machine
	careless checking on produced BMDW	Defect BMDW during packing to shipping carton		6	3	3	54	Train operators on proper quality checking for produced BMDW

irregular maintenance leads to deterioration of machine performance which leads to out-of-specs BMDW products such as being squeezed by the mattress or contaminated to oil during production process.

Methods:

- Improper storage of the BMDW
- Improper storage due to insufficient space at the warehouse contributes to the risk of out-of-spec product
- High volume ordering
- Ordering in big volume leads to rushing and insufficient time during checking by employee

As the checking is done manually, some of the product defect is not sorted properly (Fig. 4).

Working environment: Lack of space in checking the production process, together with unfriendly working environment such as heat, influence the employee performance in checking the production result.

Men

High employee turnover: Another influencing factor is high employee turnover. Changes in employees require training for new employees in order to maintain a good and sustainable checking procedure.

Negligence at work: Negligence at work is also possible due to lack of concentration at work and lack of guidance from the company.

Failure Mode Effect Analysis (FMEA): Failure Mode and Effect Analysis (FMEA) is a qualitative and systematic tool in identifying effect and consequences of a failure mode in a system or process. It can help reducing or eliminating possibility of failure. FMEA is used to identify failure of a product, service or process which can lead to minimizing its occurrences. FMEA can also be used both in designing a new system as well as improving an existing one.

FMEA uses three criteria to assess a problem:

- The severity of the effect on the customer
- How frequently the problem is likely to occur
- How easily the problem can be detected

Participants must set and agree on a ranking between 1 and 10 (1 = low, 10 = high) for the severity, occurrence and detection level for each of the failure modes. After ranking the severity, occurrence and detection levels for each failure mode, the team will be able to calculate a Risk Priority Number (RPN). The formula for the RPN is:

$$RPN = Severity \times Occurrence \times Detection$$

In this study, FMEA was used as a tool to identify which failure was the critical one and hence must be handled first. Using FMEA we can identify failure rate of a system, product or process. The method helped in identifying possible cause of failure. Determining the weight criteria of failure mode was done through discussion amongst the right people with the right experience to the system, i.e., the production manager, QC staffs and operators of the company. The result of FMEA by defect type is summarized in Table 2. From each result, a Pareto diagram is plotted and summarized in Fig. 5.

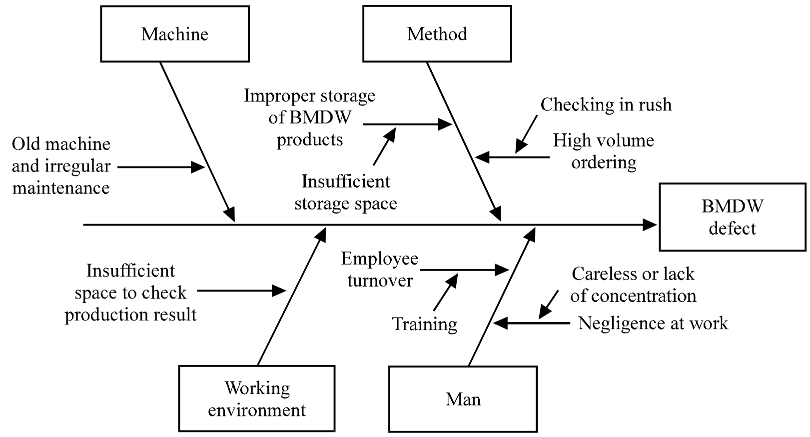

Fig. 4: Root cause analysis on BMDW defect using fish bone (Data Analysis 2014)

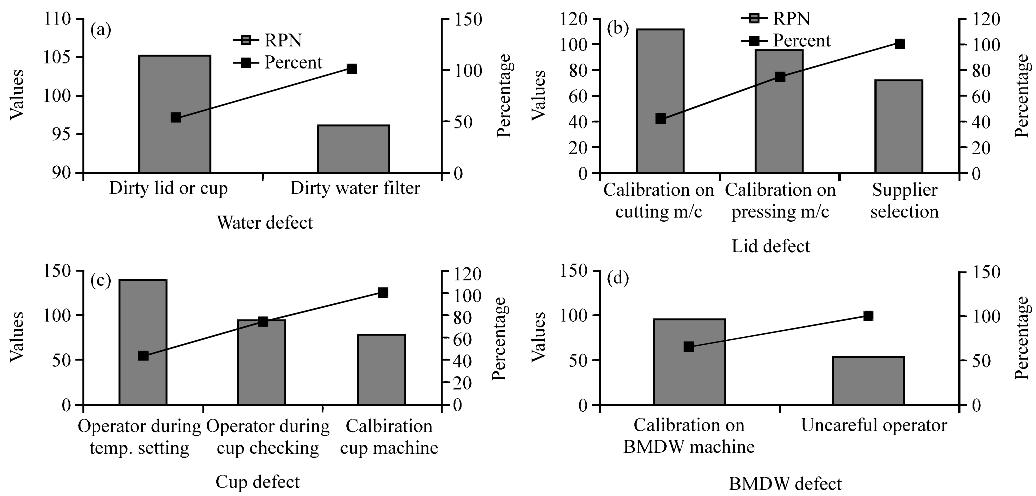

Fig. 5: Pareto chart of FMEA result by defect type (Data Analysis 2014); Remarks of CTQ as: a) Main contributor of water defect occurrence was operator carelessness with percentage of 52%. However, it was possible that water defect was originated from the water source and not the employee. Therefore, company must put a quick response against any defect occurrence; b) Main contributor of lid defect was calibration on the cutting machine (40% contribution). It was therefore, recommended for mechanics/maintenance crew to do regular checking in order to make sure all machine components is in good condition and in ready for use; c) Main contributor was operator carelessness in setting temperature at cup making machine (44%). Temperature setting is quite sensitive and delicate such that a small miss can lead to defect cups that can not be used for production. Operators were required to be very careful and precise in temperature setting; d) Main contributor for this defect was calibration on the BMDW machine (water filling process, lid pressing using the correct temperature and cutting) (64% contribution) operator was expected to be able to operate the machine correctly and according to standard

CONCLUSION

Choosing the appropriate method plays a crucial role in how to mitigate risks in a product, process or system. FMEA can be considered as a tool which can identify more risks compared to other methods. The study shows that FMEA is suitable to be used in improving the quality control of a bottled mineral drinking water firm.

In general, improvements in the study were recommended towards the "man" and "machine" factor. In "man" factor, main contributors were from operator carelessness during production process and improper machine setting which led to product defect. In "machine" factor, machine performance shown deterioration due to irregular maintenance.

RECOMMENDATIONS

Recommended actions plan to the firms in maintaining a good product quality were as following:

- Increase employee's motivation, especially for the floor shop operators. Motivation can be in form of rewards based on company's performance
- Make a clear Standard Operating Procedure (SOP) for operators, so they get a correct work guideline in operating machines properly and as per the specified standards
- Regularly give training and guidance to operators in how to handle and maintain machines properly, especially for new or unskilled operators
- Conducting regular maintenance to all the production machines
- Creating a safe and friendly working environment in the floor shop, e.g., enough ventilation to reduce heat

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