International Journal of Engineering and Environmental Sciences | *ISSN 1694-4372*
Published by AIR JOURNALS | *https://airjournal.org/ijees*
16/18 Avenue des Longaniers, Quatre Bornes, Mauritius
airjournals@gmail.com; enquiry@airjournal.org

RESEARCH ARTICLE

Using Failure Occurrence, Severity, Detection, and Risk Priority Number in Developing FMEA Worksheet in a Brewery for Failure Mitigation

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Accepted: March 4th, 2022	**Published: March 31st, 2022**

Citations - APA

Eze, M. N., and Eneh, I. I. (2022). Using Failure Occurrence, Severity, Detection, and Risk Priority Number in Developing FMEA Worksheet in a Brewery for Failure Mitigation. *International Journal of Engineering and Environmental Sciences, 5(3), 1-9.*

ABSTRACT

Failure Modes and Effects Analysis (FMEA) is a procedure by which each potential failure mode in a system is examined, its effects determined and its severity classified. FMEA Worksheet supports the process of managing the risk associated with product or process failures. In this paper, use is made of the observed values of the failure indicators namely, the Occurrence, Severity, Detection, and Risk Priority Number (RPN) in developing an FMEA Worksheet in a Brewery to bring about a considerable level of failure mitigation in a process production company. The methodology involves the identification of potential failure modes and their respective root causes, determination of the severity, occurrence, and detection, and calculation of the RPN. The RPN values show the component unit with the highest failure potential. Then, following the developed FMEA Worksheet, recommended remedial actions are taken. This presents the resulting Worksheet as a veritable tool for failure mitigation as desired.

Keywords: *Failure Modes and Effects Analysis, Worksheet, Brewery, Risk Priority Number*

1. Introduction

FMEA, an acronym for Failure Modes and Effects Analysis, is a procedure by which each potential failure mode in a system is examined to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity (Pentti and Atte, 2002). In engineering, as in any other field of human endeavour, failure is a process of technical implosion. It is indicative of a termination of a process. When the process is a dynamic production system, failure results in the complete or partial stoppage of operation and hence production. It is then said that the system has collapsed. Generally, hazards and failures in a production process affect reliability, availability, maintainability, and safety. When using the FMEA tool for every system and component, failure modes and their effects on other components and subsystems are reviewed on a worksheet (Ershadi and Ershadi, 2018). Usually, it is observed that cost of production increases during failures because output per hour falls. There is what is referred to as a high factor in production. This means that spreading the total output over the total time of normal work or operation brings a low average. Personnel redundancy quickly results as idle manpower abounds. This mainly affects the outsourced members of staff that are usually laid off during prolonged failures. Besides redundancy, skill improvement drops drastically.

There is also a drop in efficiency. This is because the Overall Equipment Effectiveness (OEE) drops. The OEE is an indicator that measures the proper and effective use of machines in relation to output recorded. When the OEE falls continuously due to prolonged failures, efficiency is said to have also dropped simultaneously, drastically, and abysmally too. There is usually a fall in quality when a failure occurs intermittently during a production cycle. This is because reliable quality control can no longer be guaranteed. A typical instance is the proper carbonation of beverage drinks which drops sharply when a failure occurs during a production cycle. Also, labeling could be inconsistent during this time. Generally, all aspects of quality measures are affected during failure periods and this is a major concern to the company. The research intends to reduce or eliminate these anomalies.
In this presentation, use is made of the observed values of the failure indicators namely, the Occurrence, Severity, Detection, and Risk Priority Number in developing an FMEA Worksheet in a Brewery to bring about a considerable level of failure mitigation in a process production company such as a brewery. The peculiar production units upon which the named indicators were measured are those found in most modern brewery line production plants. This means that the procedure described in this paper could be used in any such similar production plants with the expectation of getting similar results.

2. Review of Related Literature

Empirical Review

The following related works on the application of Failure Modes and Effects Analysis, FMEA, are presented to show the high degree of success recorded in the area of failure reduction in dynamical systems using FMEA.

In their work, "Development of FMEA Information System for Manufacturing Industry," Khairul, et al, (2014), identified defective raw materials or components and mistaken assembly processes as two reasons causing manufacturing process failures. Failure Mode and Effects Analysis tool could be applied to handle this manufacturing process failure in manufacturing industries by using it to analyze the manufacturing and assembly processes. Failure mode caused by process or assembly deficiencies was the primary focus. Based on severity, occurrence, and detection, every identified failure was rated. By recommending preventive or corrective actions, FMEA helps to improve the reliability of the manufacturing process. Using Borland Delphi Enterprise Version 5.0 programming package and Microsoft Access 2002 as database manager, the paper described the prototype development of Failure Mode and Effect Analysis Information System for the manufacturing process. This FMEA process has several problems namely, not being a living document, requires much scrolling, tedious data-keeping, no security control mechanism, limited manufacturing process data, not user friendly, unattractive interface, and less teamwork support.

In another work by Sourabh and Belokar, (2017) titled Quality Improvement Using FMEA: A Short Review, FMEA was described as a proactive, systematic method for evaluating a process to identify where it might fail to prevent the impending failure. It followed a step-wise process starting with potential failure causes, existing failures in the current working mechanism, and calculating the risk priority number, (RPN), of both the existing and modified system. To calculate the Risk Priority Number (RPN), the Severity, Occurrence, and Detection were determined. The product of the severity, Occurrence, and Detection gives the RPN. The RPN gives the component with the highest risk factor in the system process.

The next review is from a document by Siemens PLM software, (2016), on How to conduct failure models and Effects Analysis (FMEA). The document defined "failure mode" as the means of identifying defects or errors, potential or actual, in a product design or process with emphasis on those affecting the customer or end-user. Similarly, "failure effect" was also defined as the result of a failure mode on the product or system function as perceived by the user. Effect analysis was the study of the consequences of identified failures. Five process steps in FMEA analysis were also outlined. These are identifying potential failures and effects; determining the severity; gauging the likelihood of occurrence; determining failure detection and calculating the Risk Priority Number (RPN). An example was presented. Corrective measures were advanced which included the elimination of failure modes, minimizing the severity of failure modes, reducing the occurrence of failure modes, and improving detection of failure modes. The RPN should be re-calculated and results documented for subsequent use by the relevant staff in the FMEA document.

Finally, Ganesh Kondhalkar, et al, (2016) in FMEA Analysis of Modified Screw Jack for Assemblage of Shell and Tube Heat Exchanger, described FMEA, also known as FMECA, as a systematic method by which potential failures of a product or process design are identified, analyzed and documented. FMEA methodology and its implementation in the processing industry to modify conventional screw jack for assembly problem elimination in shell and tube heat exchangers were described. It is a crucial reliability tool that helps to avoid costs incurred from product failure and liability. The main aim of the work was to show risk prioritization using the FMEA method. It was used to identify and eliminate potential problems facing a manufacturing process for improving the reliability of subsystems to ensure quality.

In all these reviews, the use of the FMEA indicators namely, severity, occurrence, detection, and evaluable Risk Priority Number, RPN, were shown to be very handy in the determination of failure modes and their associated consequences in manufacturing and process companies. Thereafter, these indicators were used in developing FMEA Worksheet for use in addressing failure issues with a view to mitigating their continued menacing effects as identified.

3. Methodology

The indicators in the failure analysis process namely, severity, occurrence, detection, and the risk priority number are clearly defined to properly assert them in their respective schemes. Table 3.1 shows the categorization of severity as a failure indicator.

Table 3.1: Categorization of the Severity of a failure (Source: IMCA M 166, April 2002).

Category	Degree	Description
i.	Minor	Functional failure of a part of a machine or process with no injury potential, damage, or pollution.
ii.	Critical	Failure occurrence without major damage to the system, pollution, or serious injury.
iii.	Major	Major damage to the system with potential for serious injury to personnel and minor pollution.
iv.	Catastrophic	Failure causes complete system loss with a high potential for fatal injury and major pollution

In table 3.1, the level of severity of the failure itself depends on the seriousness of its resulting effect. Thus, they are categorized as minor, critical, major, and catastrophic. After that, the procedure taken in carrying out failure evaluation is outlined in the order as presented.

FMEA Procedure

There is a procedure that is followed in carrying out the FMEA process. This procedure is aimed at carrying out a dependable analysis of the failure occurrences, their severity, and the likelihood of detection. The end result is to arrive at a position that ultimately mitigates failure thereby improving operational activities. The procedure is hereby presented.

1. A review of the product or process design is first undertaken with a view to understanding it as it is broken down into components (products) or steps (process).

2. A brainstorming session is carried out on the modes of failure.

3. The severity of each effect of failure is rated.

4. The likelihood of occurrence of each failure is also rated.

5. The likelihood of detection of each cause of failure is also rated to show its likelihood of detection before the customer or operator is affected.

6. The Risk Priority Number, RPN is then computed as RPN = Severity x Occurrence x Detection.

7. Having determined the highest RPN value, apply corrective measures or actions then minimize the occurrence of the most significant failure mode(s).

8. Apply another FMEA re-assessment on the product or process to monitor the progress made.

9. Regular re-assessment of failure analysis could be carried out as the need arises.

10. Rating or ranking conventions are based on 1 = low and 10 = high on a 1 – 10 scale.

11. Create mitigation plans for the potential failures with the highest RPN.

Following the above procedure, a painstaking study of a typical beverage manufacturing company was carried out with a view to showing how the indicators faired during production activities. These were eventually used to ascribe values to severity, occurrence, and detection after which the risk priority number was calculated. In this work, the units which were considered are

I. The Uncaser
II. Bottle Transport Conveyors
III. Bottle Washer
IV. Filler
V. Coding Machine

All the units were for Returnable Glass Bottle, RGB, Line 1. Results obtained in failure records involving these indicators are further used in failure calculations of the RPN and subsequently, the FMEA worksheet as required in this presentation. Criteria for carrying out failure analysis using these indicators are shown tabulated in table 3.2.

Table 3.2 Criteria for Analysis

Criteria	Description	Low Number	High No
Severity	This involves what is important to the industry, company, or customers. These include safety standards, environment, legal, production continuity, scrap, loss of business, and damaged reputation.	Low Impact.	High Impact
Occurrence	Rank the probability of a failure occurring during the expected lifetime of the product or service.	Not likely to occur. Low impact.	Inevitable. High Impact.
Detection	Rank the probability of detecting the problem before it happens.	Very likely to be detected. High Impact.	Not likely to be detected. Low Impact.

Measurement of Downtime in Hours and relationships with the FMEA indicators
It was undertaken to carry out real-time measurements of the actual downtime observed in hours.

Table 3.3: Period One: January 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Classification (Occurrence)	Rating
1	Uncaser	18.45	Unavoidable Failure	Very High	10
2	Bottle Transport Conveyors	38.03	Unavoidable Failure	Very High	10
3	Bottle Washer	25.49	Unavoidable Failure	Very High	10
4	Filler	12.71	Unavoidable Failure	Very High	10
5	Coding Machine	4.35	Frequent Failure	High	8
	Total	97.03			

Table 3.4: Period Two: February, 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Description (Occurrence)	Rating
1	Uncaser	7.48	Unavoidable Failure	Very High	10
2	Bottle Transport Conveyors	34.7	Unavoidable Failure	Very High	10
3	Bottle Washer	8.62	Unavoidable Failure	Very High	10
4	Filler	17.37	Unavoidable Failure	Very High	10
5	Coding Machine	2.92	Rare Failure	Moderate	4
	Total	71.09			

Table 3.5: Period Three: April 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Description (Occurrence)	Rating
1	Uncaser	6.55	Unavoidable Failure	Very High	10
2	Bottle Transport Conveyors	62.3	Unavoidable Failure	Very High	10
3	Bottle Washer	6.42	Unavoidable Failure	Very High	10
4	Filler	16.38	Unavoidable Failure	Very High	10
5	Coding Machine	8.43	Unavoidable Failure	Very High	10
	Total	100.08			

Table 3.6: Period Four: April 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Description (Occurrence)	Rating
1	Uncaser	6.74	Unavoidable Failure	Very High	10
2	Bottle Transport Conveyors	49.55	Unavoidable Failure	Very High	10
3	Bottle Washer	7.89	Unavoidable Failure	Very High	10
4	Filler	4.8	Frequent Failure	High	8
5	Coding Machine	1.29	Unlikely Failure	Minor	2
	Total	70.27			

Table 3.7: Period Five: May 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Description (Occurrence)	Rating
1	Uncaser	0.83	Unlikely Failure	Minor	2
2	Bottle Transport Conveyors	20.22	Unavoidable Failure	Very High	10
3	Bottle Washer	2.85	Rare Failure	Moderate	4
4	Filler	3.37	Irregular Failure	Major	6
5	Coding Machine	0.33	Unlikely Failure	Minor	2
	Total	27.6			

Table 3.8: Period Six: June 2018

S/N	Fault Description (Component Unit)	(Hours) Downtime	Severity Effect (Severity)	Description (Occurrence)	Rating
1	Uncaser	3.87	Irregular Failure	Major	6
2	Bottle Transport Conveyors	25.42	Unavoidable Failure	Very High	10
3	Bottle Washer	5.21	Unavoidable Failure	Very High	10
4	Filler	2.98	Rare Failure	Moderate	4
5	Coding Machine	3.09	Irregular Failure	Major	6
	Total	40.57			

Tables 3.3 to 3.8 show the actual results of monitoring production operations in a bottled beverage manufacturing company in the first half of the year 2018. The five-line production units which were considered in RGB Line 1 were particularly monitored and results were recorded with respect to the actual length of downtime in hours during each month from January to June 2018. It is important to define the conditions under which data and information in tables 3.3 to 3.8 were arrived at. The actual downtime values were used as determining conditions as described below.

I. Downtime values of more than 5 hours are considered to have a severity effect of unavoidable failure with occurrence classification of very high and detectability of very high.
II. Downtime of 4 hours has a frequent failure possibility as a severity condition with a high rate of occurrence.
III. Downtime of 3 hours has irregular failure severity level and major occurrence rate.
IV. Downtime of 2 hours plus has a rare failure severity level and moderate occurrence rate.
V. Downtime value of fewer than 2 hours has unlikely failure severity and minor occurrence rate.

Using the above conditions, the data obtained were then summarized and used to get the data in table 3.9. An extension of the data in this table is the value assignment of the detection indicator as well as the subsequent calculation of the Risk Priority Number, RPN. Using the data contained in the table, the FMEA Worksheet was developed.

Table 3.9: Summary of Cumulative Downtime of RGB Line 1

Component Unit	1st	2nd	3rd	4th	5th	6th	S	O	D	RPN
Uncaser	10	10	10	10	2	6	6	6	4	144
B.T.C	10	10	10	10	10	10	10	10	2	200
Bottle Washer	10	10	10	10	4	10	9	9	2	162
Filler	10	10	10	8	6	4	8	8	2	128
Coding Machine	8	4	10	2	2	6	5	5	2	50

Development of FMEA Worksheet for the Already Identified Failure Types
FMEA Worksheet supports the process of managing the risk associated with product or process failures. It is particularly useful in assessing the risk of a lean project.
The basic steps undertaken to develop and apply the FMEA Worksheet in this work are as follows:
I. Identification of all failure modes in the entire system as it concerns the components under study.

II. Consideration of the root causes of the identified failure modes by individual analysis.

III. Carry out an in-depth and comprehensive assessment of the risks involved in the failures of each of the components under consideration to determine the severity, occurrences, and detection of each of the component units.

IV. Having determined the failure parameters of severity, occurrence, and detection, a calculation of the Risk Priority Number, RPN, is carried out after which the failure modes were ranked according to the value of the RPN.

V. Outline the steps taken in the course of developing the FMEA Worksheet to eliminate the risks thereby minimizing failure modes in the production process of the company.

Following the outlined conditions, the FMEA Worksheet for the unit components understudy in RGB Line 1 production is as shown in table 3.10.

Table 3.10: FMEA Worksheet for the Component Parts Investigated in RGB Line One

Unit or Component	Operational Function of part or component	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause of Failure	O	Current Process Control	D	RPN
Uncaser	De-crates empty bottles to bottle washers.	Uncaser Table Conveyor jerking	Bottles falling	6	Uncaser table conveyor sensor fault	6	Check and chain condensate bottle trap.	4	144
Bottle transport conveyor	Conveys empty bottles to filler & packer.	The bottle conveyor tripped off.	Guideline's conveyor falling bottles	10	Drive bearing collapse.	10	Reduction of various elongated conveyor chains.	2	200
Bottle washer	Washes used empty bottles for use again.	Washer discharge jam	Bottle hook at glideliner	9	Caustic tank strainers dirty.	9	Clean strainers of caustic tanks.	2	162
Filler	Fills empty bottles to the required capacity.	Filler bottle jam	Many half-filled bottles coming out.	8.	Main drive belt problem.	8	Vent mesh and clean main drive propeller.	2	128
Coding machine	Prints appropriate coding information on filled bottles.	Illegible printing	Very faint printings on bottlenecks.	5	Ink stream pressure is poor.	5	Set ink stream pressure at 40 psi	2	50

4. Analysis and Discussion

As shown in the FMEA Worksheet of table 3.10, the first column is the units or components under study. The second, third, and fourth columns contain the operational functions of the parts or units under study, the associated potential modes, and potential failure effects, respectively. Specifically, column two gives the direct function of a particular unit as used during the production process. This is followed by an identification of the specific failure and its actual mode as it affects production. Column four gives the potential effects of the identified failure and mode. With these first four columns of table 3.10 digested, the severity becomes clear and a value assignment was given to it accordingly.

After this phase, the need to identify the potential cause of failure becomes necessary. This was done for each of the component units followed by the determination of the frequency of occurrence of each failure event. A numerical value was assigned to this for evaluation purposes. Thereafter, a current process control measure for mitigation of failure was proposed for implementation. This was followed by the level of detection and assignment of value to it. With these values of severity, occurrence, and detection known, the risk priority number, RPN, was calculated. The following formula was used.

Severity x Occurrence x Detection = Risk Priority Number or (S x O x D = RPN).

A continuation of the production process after these activities will bring about a reduction in the numerical assigned values for severity, occurrence, and detection thus, reducing the calculated value for the RPN. This ultimately brings about failure mitigation which is the desired condition in a bottled beverage company and similar companies. Figure 1 shows a bar chart representation of the successful development of the FMEA Worksheet of table 3.10.

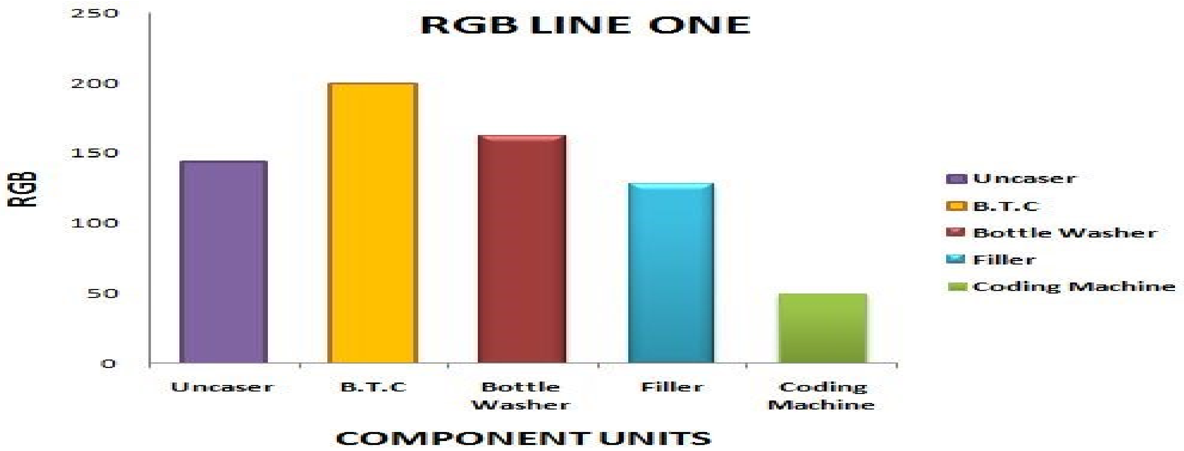

Figure 1: Bar Chart representation of the FMEA worksheet for RGB Line One

5. Conclusion

To mitigate failure occurrences in process and manufacturing industries, the FMEA Worksheet has been proved to be a veritable tool. As shown, FMEA Worksheet supports the process of managing the risks associated with product or process failures in a manufacturing company. A redesign of the component units, by way of carrying out the proposed current control measures on the component units investigated in this work, is recommended so that an appreciable failure mitigation result would be achieved.

References

Alan S. Willsky (1976). A Survey of Design Methods for Failure Detection in Dynamic Systems. *Automatica*, 12: 601-611. Pergamon Press, 1976. Printed in Great Britain.

Deyun Zhou, Yongchuan Tang, and Wen Jiang (2016). A Modified Model of Failure Mode and Effects Analysis Based on Generalized Evidence Theory. *Mathematical Problems in Engineering,* 2016, 11 pages, *http://dx.doi.org /10.1155/2016/4512383.*

Ershadi M.J. and Ershadi M.M. (2018). Implementation of Failure Modes and Effects Analysis in Detergent Production Companies: A Case Study; Wiley Inc. Publications

Ganesh E. Kondhalkar, Dhananjay R. Barde, Akshay R. Pawar, Kapil S. Shan. (2016). FMEA Analysis of Modified Screw Jack for Assemblage of Shell and Tube Heat Exchanger. *International Journal of Engineering Science and Computing*.

Khairul Annuar bin Abdullah, Jafri Bin Mohd.Rohani and Mohd. Salihin bin Ngadiman (2005). The Development of FMEA Information System for Manufacturing Industry, *Research Gate Publications*

Lee H, Lee H, Baik J, Kim HJ and Kim R (2017). Failure mode and effects analysis drastically reduced potential risks in clinical trial conduct; Dovepress Publications, 2017.

Pentti, H. and Atte, H. (2002). Failure Mode and Effect Analysis of Software-based Automation System, STUK-YTO-TR 190, 1-37.

Sellappan N. and Palanikumar K. (2013). Modified Prioritization Methodology for Risk Priority Number in Failure Mode and Effects Analysis. *International Journal of Applied Science and Technology*, 3(4).

Siemens PLM Software (2016). How to Conduct a Failure Modes and Effects Analysis (FMEA). A White paper issued by Siemens Product Lifecycle Management Software Inc. © 2016.

Sourabh Rana and Belokar R.M. (2017). Quality Improvement Using FMEA: A Short Review. *International Research Journal of Engineering and Technology (IRJET)*, 04(06).

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