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APPLICATION OF THE FMEA METHOD FOR THE ANALYSIS OF INACCURACIES IN THE MANAGEMENT OF EMPTY CONTAINER MOVEMENT: A CASE STUDY

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ABSTRACT

The objective of this paper is to describe the use of Failure Mode and Effect Analysis (FMEA) method to manage the process of empty container movement in a logistics company that operates, among other logistic activities, as an Empty Container Terminal. Thus, we sought to identify and classify the potential failure modes that may occur during the process. The case study consisted of the application of a semi-structured questionnaire, which was directed to the multidisciplinary team composed of eight employees of the company under study. With the help of professionals in the field, twenty potential failure modes were identified, which, adapted to the reality of the company studied, were classified according to severity, occurrence and detectability. From the five potential failure modes with the highest Risk Priority Number (RPN), the causes and effects were identified. Thus, suggestions for corrective measures that can be adopted by the company to minimize the effects of failures, improve company productivity and decrease the process lead time were listed. For future work, it is suggested to apply the corrective measures listed in this research and to compare the scenarios to verify improvements in the process, productivity and quality of service provided.

Keywords: FMEA; Containers; Failure analysis; Quality in services; Failure Prevention.

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1. INTRODUCTION

Ports, port terminals and port-backup integrate the Brazilian logistics infrastructure necessary for the economic development of the country, through the national and international cargo movement. According to the waterway statistical yearbook of the National Waterway Transportation Agency (ANTAQ, 2017), in 2017 there was a total cargo movement in organized ports and private terminals of 1.086 billion tons. When compared to 2016, there was an increase of 8.3% in total cargo movement.

Containers are used to carry cargo in ports, as they are reusable multimodal cargo equipment that requires proper storage and maintenance. Thus, after being used, containers should proceed to their respective Empty Container Terminals, which specialize exclusively in moving, repairing, storing and releasing empty units.

The process of managing the movements and the allocation of empty units in the yard of the Empty Container Terminals is carried out by the verifier. The verifier is responsible for coordinating the forklifts and determining the location of each batch of containers. However, there is no internal tracking of containers at Terminals, the systems generally used in Brazil allow only determining unit status (awaiting inspection, damaged, repaired, or awaiting release). In this sense, the exact location cannot be verified electronically, only visually or through the verifier, making the process complex and prone to failure.

Given this scenario, the objective of this paper is to apply the Failure Mode and Effects Analysis (FMEA) tool for the analysis of empty container movement failures, aiming at the optimization of the management processes in an Empty Container Terminal.

This article is divided into five sections. After the introductory framework, there is section 2, which presents the theoretical framework. Section 3 discusses the methodology. Section 4 presents the case study as well as the results obtained. And finally, section 5 describes the final considerations, limitations, and recommendations for future research.

2. THEORETICAL REFERENCE

To define the failure analysis tool, the bibliometric study performed by Gomes *et al*. (2016) was used. This research defines a bibliographic portfolio about the use of failure analysis methods in the management of empty container handling. Thus, it was identified, among the 49 articles that made up the bibliographic portfolio, that the FMEA method was the most used. In view of this, the FMEA tool combined with the Risk Priority Number (RPN) was chosen to perform the analysis of potential failures that may occur during the process of moving empty containers.

FMEA is an important technique that identifies known or potential failures to increase the reliability and security of complex systems and thus is intended to provide information used in decision making regarding risk management. Liu *et* al. (2013) define FMEA as a risk assessment tool that mitigates potential failures in systems, processes, projects or services.

Thus, the goal of FMEA is to prioritize product or system failure modes in order to assign limited resources to items of serious risk. In general, the prioritization of failure modes for corrective actions is determined through RPN, which is obtained by multiplying the values assigned to the severity, occurrence and detectability of a failure.

The FMEA process consists of five steps, which are: choosing a process to study, assembling a multidisciplinary team, collecting and organizing information about the process studied, performing fault analysis, and finally developing corrective measures. (Chiozza e Ponzetti, 2009; Cicek e Celik, 2013).

Given the above, the FMEA methodology is important as it provides the company with a systematic way to catalog information about product/process failures; improves knowledge of product/process issues; generates improvement actions in product/process design, based on data and properly monitored (continuous improvement); entails cost reduction by preventing the occurrence of failures; and there is the benefit of incorporating within the organization the failure prevention attitude, the cooperative and teamwork attitude, and the concern for customer satisfaction (Silva *et al*., 2008).

Figure 1 describes the main characteristics of the FMEA method proposed by Apkon *et al*. (2004).

3. METHODOLOGY

The methodological framework of the research is defined based on the purpose of the project, the character, the research design, the collection techniques and the data analysis to be used (Roesch, 2005).

In this article, the purpose of this research is to obtain information about a certain population. (Roesch, 2005). The population is composed of the employees of the study company who work in the process of moving empty containers, and the sample is composed of the employees

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Features of Failure Mode and Effects Analysis (FMEA)
Characterize process elements or steps
Identify failure modes
For each process element, mark between 1 and 10 on the points scale:
-Failure severity (S) that should not be detected;
-Probability of occurrence (O) for each basis in experience, measurement, and literature;
-Likelihood that faults will not be detected (D) before causing damage
For each element calculate a number of risk priorities (RPN) = SxOxD
Prioritize corrective measures for elements with higher RPN

Figure 1. Features of *Failure mode end effect analysis* (FMEA)

Source: Made from Apkon *et al*. (2003)

who made up the multidisciplinary team, who were the respondents of the data collection instrument.

The research is characterized as its purpose as applied research; however, its objective is to identify flaws in the process of an organization. The study has a qualitative and quantitative character, since it seeks to classify the potential failure modes regarding severity, occurrence and detectability, by calculating the established score.

As for the design, the case study method is used in order to study the potential failure modes in the process of moving empty containers. Regarding data collection techniques, it was based on the application of questionnaires, interviews and direct observation of the process. Finally, for the data analysis techniques, statistical methods were used that allowed calculating the RPN.

4. CASE STUDY

This section is divided into eight subsections that describe the steps of the case study. The first presents the definition and the period of study. The following subsection discusses the research application schedule and the FMEA method. The third subsection demonstrates the operational characterization of the company and the analysis of the empty containers movement process in the studied company. The fourth subsection describes the composition of the multidisciplinary team and the goals. The fifth subsection presents the potential failure modes raised. The sixth demonstrates the application of the data collection instrument. In the seventh subsection, data analysis is performed. Finally, the last subsection describes the causes, effects and corrective measures raised by the multidisciplinary team.

Definition and period of study

The study was carried out in a logistics company, located in the Distrito Industrial neighborhood of the city of Rio Grande, in the state of Rio Grande do Sul, which provides storage and handling services for full and empty containers.

Data collection and analysis was limited to the process of moving empty containers. Thus, a multidisciplinary team was selected, with employees from different sectors and who had knowledge of all stages of the process.

Regarding the study period, it was held from September 13 to October 8, 2016, according to the schedule established in the following subsection.

Case Study Schedule

To perform the analyzes, seven visits to the company were made to apply the failure analysis method. Figure 2 shows the schedule for conducting the study.

Operational characterization of empty container handling

During the second visit to the company, the general manager of the container handling process was interviewed about the operational characteristics of the company. Figure 3 shows the characteristics observed from the interview.

The description of the process and the sectors involved was done jointly. They are: Gate in, Survey, Patio, Workshop, and Gate out. Figure 4 shows the process observed and described by the employee.

Container (in) entry is the first phase of the container movement process in an empty container terminal. In this sense, the arrival of the empty container to the terminal can occur in two ways: as import return or empty discharge, which is the form used by shipowner s to carry out the repositioning of containers.

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Visits	Data	Schedule / Description
1st day	Sept 13	a. authorization request for search application
		b. authorization request for search application
2nd day	Sept 19	a. company characterization
		b. Identification of Container Handling Process Steps
3rd day	Sept 20	a. formation of multidisciplinary team
		b. team analysis regarding identified potential failure modes
4th day	Sept 21	a. delivery of the data collection instrument to the multidisciplinary team
5th day	Sept 30	a. return of the data collection instrument delivered
6th day	Oct 7	a. identification of causes and effects of potential failure modes with higher NRP by the multidisciplinary team
		b. suggestions for improvements
7th day	Oct 8	a. identification of causes and effects of potential failure modes with higher NRP by the multidisciplinary team
		b. suggestions for improvements

Figure 2. Schedule

Source: The authors themselves

Company operational characteristics
ERP system used: Modal Port
Storage Capacity: 8,000 TEUs
Number of receipts and unit handling: about 150 TEUs / day
Número de reparos: cerca de 80 TEUs/dia
Number of Employees: 65 Employees
Number of machines: six machines (three large and three medium)
Number of repair shops: three repair shops
Number of shipowners served: seven shipowners
Survey: Outsourced
Communication: via radio

Figure 3. Company operational characteristics

Source: The authors themselves

In view of this, in the process of unloading empty containers, the terminal is informed by the shipowner as to the quantity and number of each unit to be shipped. However, in the process of import return, the container is returned to the terminal of its respective owner, where the information is transferred to the terminal. As soon as the terminal becomes aware of empty container unloading, the Gate In sector arranges for the withdrawal of containers. Finally, the trucks are shipped to transport the units to the terminal, and thus the units start entering the container management system.

In the second part of the process, when the unit is returned by the importer, it will only effectively enter the terminal after rigorous inspection and, if any malfunctions committed by the importer are detected, it must bear the costs of repairs so that the container can be received by the terminal. In the terminal case study, the survey is performed by an outsourced company. Containers are identified by surveyors with colored ribbons, depending on the type of damage, and are moved to their respective lots.

Soon after, as a third part of the process, the surveys are sent to the Repair Estimation sector and the damages and their respective repairs are added to the system. Finally, the values are estimated and passed on to the shipowner for repair authorization.

In the fourth step of the process, units with authorized repairs are placed in the workshop, accompanied by their service order issued by the estimation department, which contains all the information regarding the repairs to be performed.

Finally, out is the fifth step in the process, empty units can be released, as instructed by the shipowner, as export or shipment of voids for repositioning containers at another terminal of the same shipowner. This shipowner sends the terminal the booking with all information about the units for release: quantity, standard, capacity, date of shipment, ship, and customer name.

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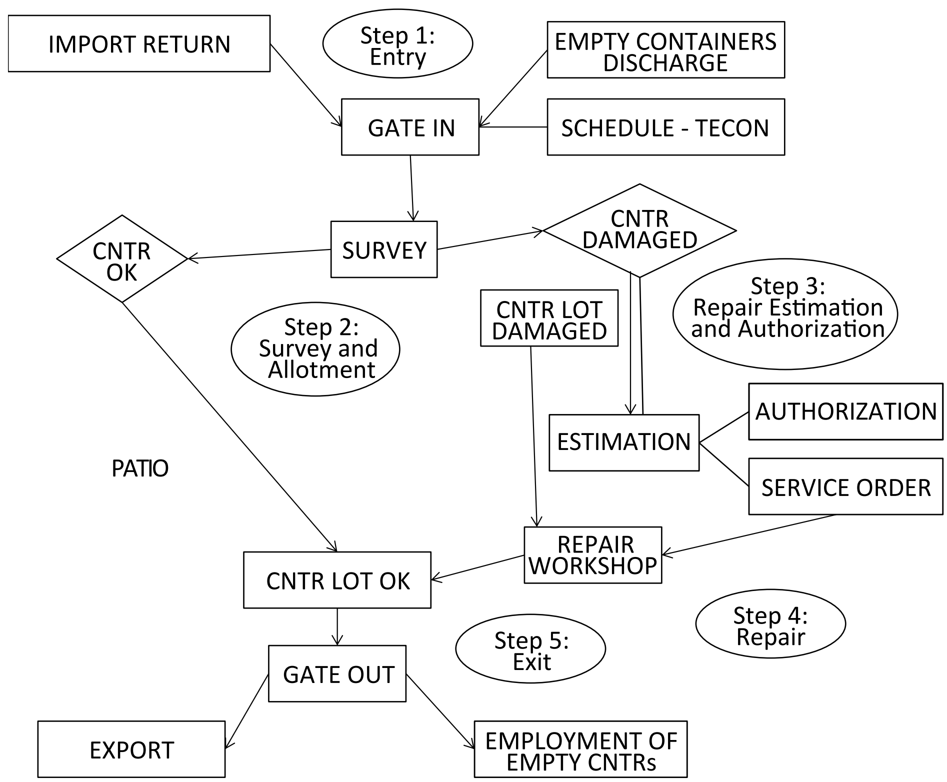

Figure 4. Process Flowchart
Source: The authors themselves

Also regarding the out process, about emptying the shipment, the shipowner informs the terminal of the quantity, pattern, status and capacity of the units to be shipped. The Gate Out department passes on to the verifiers the information contained in each of the bookings received, so that they can load the containers with the required characteristics. However, still in the Gate Out sector, the containers are removed from the system and the numbered seal of the respective shipowner is delivered. Finally, the empty boarding units are released without seals.

Team Composition

During the third visit to the company, the multidisciplinary team, consisting of eight company employees, directly involved in the process of moving empty containers, was determined. In this regard, a gate-in employee, a gate-out employee, two estimation employees, a checker, a general officer and a workshop officer were selected. The general manager has been defined as the team leader.

Raised potential failure modes

On the third day of the visit, the members of the multidisciplinary team were presented with the twenty potential failure modes raised by the researchers with the help of professionals in the field.

The team analyzed the potential failure modes presented, and therefore made their contributions. In view of this, the potential failure modes were adapted to the reality of the company and were listed as follows:

1. Malfunctions during the movement of the units;

2. Units stored in incorrect batch;

3. Units loaded for release outside FIFO;

4. Delay in loading or unloading units due to lack of machinery;

5. Delay in loading due to lack of units ok or specific pattern;

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6. Number of units scheduled for release in TECON, exceeding the operational capacity of the terminal;
7. Damage to transported goods detected at destination due to damage to the unit;
8. Unnecessary movement of units;
9. Not locating units for release;
10. Use of incorrect equipment when moving units;
11. Malfunctions not noticed during the survey;
12. Units positioned in workshop without authorization for repairs and work order;
13. Repair or upgrade not included on the work order;
14. Unit returned by customer for non-standard or defective;
15. Delay in repairs due to lack of material or personnel;
16. Repairs that were on the work order and were not performed;
17. Release of numbered seal or divergent shipowner out of container;
18. Unit released from a different owner than that stated in the booking;
19. Unit released with a load capacity different from the capacity required in booking;
20. Estimated divergent repair of the survey.

The twenty potential failure modes listed were used in the data collection instrument and then team members performed the classifications.

Data collection instrument application

On the fourth visit, the data collection instrument, consisting of a semi-structured questionnaire, was delivered to each member of the multidisciplinary team. The application of the questionnaire aimed to classify the potential failure modes, listed from the scores in relation to severity (S), occurrence (O) and detectability (D), in the context of the empty container movement process.

The severity classification and detectability of potential failure modes of the empty container handling process were adapted from Jiang *et al*. (2015), as well as the classification of the occurrence of potential failure modes was adapted from Apkon *et al*. (2003).

In view of this, Figure 5 describes the severity scoring system for the five effects identified in the process of moving empty containers.

Figure 6 describes the scoring system, regarding the occurrence of failure modes in the process of moving empty containers.

Figure 7 shows the scoring system for detection of failure modes in the empty container handling process.

In this sense, the questionnaires were collected on the fifth day of visit, in which all the instruments delivered returned answered, as instructed. Thus, data analysis was performed based on the classification of potential failure modes, performed by the multidisciplinary team components.

Data analysis

To perform the data analysis, a score of severity (S), occurrence (O) and detectability (D) was established for each potential speech mode, from the average score of all respondents for each potential failure mode item analyzed.

After gathering the information, the calculation for each potential failure mode was performed, identifying the RPN. Thus, Equation 1 was used for RPN calculation.

$$(RPN)=G*O*D \qquad (1)$$

After the RPN calculation, the most relevant failure modes for the process were identified, according to the ranking presented in Table 1.

Causes, effects and corrective measures

In the last two visits to the company, the multidisciplinary team was presented with the ranking of potential failure modes. Therefore, the company was asked to analyze and identify the causes and effects of the five most relevant potential failure modes. Finally, suggestions for corrective measures for such potential failure modes were requested.

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Description	Score
No effect	1
Short process delay, no customer damage	2 – 4
Short delay in process and consequently in releases	5 – 6
Overload on terminal sectors	7 – 8
Short process delay, leading to loss of shipment	9 – 10

Figure 5. Severity (S) scoring system using FMEA

Source: The authors themselves

Possibility	Description	Score	Probability
Remote	No known occurrences	1	1/10.000
Low	Possible occurrence, but no data	2 – 4	1/5.000
Moderate	Infrequent occurrence	5 – 6	1/200
High	Frequent Occurrence	7 – 8	1/100
Very high	Almost certain to occur	9 – 10	jan/20

Figure 6. Probability of Occurrence (O) scoring system using FMEA

Source: The authors themselves

Description	Score
Absolute certainty of detecting failure	1
Moderately high chance of detecting failure	2 – 4
Low chance of detecting failure	5 – 6
Remote possibility to detect fault	7 – 8
Unable to detect failure	9 – 10

Figure 7. Detectability (D) scoring system using FMEA

Source: The authors themselves

Figure 8 shows the effects generated by the potential failure mode ranked first in the most relevant ranking, its possible causes of occurrence, and corrective measures suggested by the multidisciplinary team.

Figure 9 shows the effects generated in the potential failure mode, which are considered the second most relevant ranking. In view of this, the possible causes of occurrence and the corrective measures suggested by the multidisciplinary team are described.

The effects generated by the third most relevant potential failure mode are represented in Figure 10. In this sense, the possible causes of occurrence and the corrective measures suggested by the multidisciplinary team are described.

Figure 11 shows the effects generated by the potential failure mode, ranked as the fourth most relevant ranking, its possible causes of occurrence, and corrective measures suggested by the multidisciplinary team.

Finally, Figure 12 demonstrates the effects caused by the fifth most relevant potential failure mode. Together, there are possible causes of occurrence and corrective measures suggested by the multidisciplinary team.

At the end of the analysis, team members suggested formally recording failure modes as a way to control and correct them in the process.

5. FINAL CONSIDERATIONS

This paper aimed to apply the FMEA failure analysis method combined with the RPN method in the process of empty container handling in a logistics company located in the south of Rio Grande do Sul state.

Throughout the study, with the help of a multidisciplinary team, it was possible to identify 20 potential failure modes in the empty container handling process of the analyzed company. From the identification, the modes were classified according to severity, occurrence and

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Potential Failure Mode	Effects	S	Causes	O	Corrective Measures	D	RPN
1º - Unnecessary unit movements	Interruption of processes; Delay in the process; Unit failures; FIFO Loss	6,375	Units stored in incorrect batch; Incorrect batch formation; Lack of attention	5,25	Correct allotment of units; Greater interaction between verifier and operator; Batch identification; Radio on each machine	2,5	83,7

Figure 8. Unnecessary unit movements

Source: The authors themselves

Potential Failure Mode	Effects	S	Causes	O	Corrective Measures	D	RPN
2º - Repair estimate differs from survey	Malfunctions without repair; Repairs on behalf of the workshop; Process Delay	6	Lack of attention; Illegible surveys; Lack of training	3,375	Interaction between survey and estimation; Radio in the survey sector	3,13	63,3

Figure 9. Repair estimate differs from survey

Source: The authors themselves

Potential Failure Mode	Effects	S	Causes	O	Corrective Measures	D	RPN
3º - Unit released with load capacity different from the capacity required in booking	Return of the unit; Delay in the process; Rework	6,5	Lack of attention of verifier and Gate Out; Incorrect information; Lack of information	3,25	Verifier's access to booking; Information Improvement	2,88	60,7

Figure 10. Unit released with load capacity different from capacity required in booking.

Source: The authors themselves

Potential Failure Mode	Effects	S	Causes	O	Corrective Measures	D	RPN
4º - Ship-owner unit released differs from booking	Return of the unit; Seal exchange; Release delay; Rework	6,5	Lack of attention of the verifier; Incorrect information; Lack of information	3,25	Verifier's access to booking; Information Improvement	2,88	60,7

Figure 11. Released shipowner unit differs from booking

Source: The authors themselves

Potential Failure Mode	Effects	S	Causes	O	Corrective Measures	D	RPN
5º - Malfunctions not noticed during the survey	Return of the unit; Seal exchange; Release delay; Rework	6,5	Lack of attention of the surveyor; Shortage of surveyors; Several units for inspection; Badly damaged units; Difficult to detect malfunctions	3,25	Surveyor training; Larger number of surveyors; Surveys performed by more than one surveyor; 2nd inspection in very damaged units; Own survey	2,88	60,7

Figure 12. Malfunctions not noticed during the survey

Source: The authors themselves

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Table 1. Ranking of Potential Failure Modes

Ranking of Potential Failure Modes		G	O	D	RPN
1°	Unnecessary Unit Moves	6,375	5,25	2,5	83,7
2°	Repair Estimate Diverge from Survey	6	3,375	3,125	63,3
3°	Unit released with load capacity different from capacity required in booking	6,5	3,25	2,875	60,7
4°	Released shipowner unit differs from booking	7,625	3,125	2,125	50,6
5°	Malfunctions not noticed during the survey	4,5	3,875	2,75	48
6°	Damage to transported goods detected at destination by damaged unit	5,875	2,75	2,625	42,41
7°	Units stored in incorrect batch	5,88	5,25	1,38	42,41
8°	Repairs that were on the work order and were not performed	5,5	4,125	1,75	39,7
9°	Loading delay due to lack of units ok or specific pattern	4,875	4,125	1,75	35,2
10°	Units loaded for release outside FIFO	5,25	3,75	1,625	32
11°	Units positioned in workshop without service and repair authorization	4,625	4,75	1,375	30,2
12°	Numbered seal release or shipper divergent from what was reported on container out	5,5	3,375	1,5	27,8
13°	Carrying out repairs or upgrade that are not in service order	2,25	3	3,5	23,6
14°	Unit returned by the customer for being non-standard or damaged	4	3,375	1,75	23,6
15°	Unable to locate units for release	4,5	2,5	2	22,5
16°	Delay in repairs due to lack of material or personnel	4,625	3,125	1,5	21,7
17°	Incorrect equipment use when moving units	3,5	2,25	2,375	18,7
18°	Delay in loading or unloading units due to lack of equipment	4	3,875	1,125	17,4
19°	Number of units scheduled for TECON release, greater than terminal operating capacity	4,125	2,75	1,5	17
20°	Malfunctions while moving units	2,63	3,25	1,38	11,7

Source: The authors themselves

detectability. Thus, the five failure modes most relevant to the process were observed, and then the multidisciplinary team identified their causes and occurrences of the failure modes and the effects they generated in the process.

The identification of the five most relevant potential failure modes made it possible for multidisciplinary team members to suggest corrective measures that could be applied in the process. However, the observed measures aimed to minimize or even eliminate potential failure modes, as well as increase company productivity, decrease process lead time, improve service quality, improve information quality, and increase interaction between sectors.

The main limitation found during the study was the lack of formal registration of the company regarding the failures in the empty container handling process. In this sense, it is suggested for future work the application of corrective measures, in order to verify whether there has been improvement of the process, productivity and quality of service / process.

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