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

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.
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...
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.
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.
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;
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;


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 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.

\[(RPN)=G\times O \times D\] (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.
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
<table>
<thead>
<tr>
<th>Potential Failure Mode</th>
<th>Effects</th>
<th>S</th>
<th>Causes</th>
<th>O</th>
<th>Corrective Measures</th>
<th>D</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1º - Unnecessary unit movements</td>
<td>Interruption of processes; Delay in the process; Unit failures; FIFO Loss</td>
<td>6,375</td>
<td>Units stored in incorrect batch; Incorrect batch formation; Lack of attention</td>
<td>5,25</td>
<td>Correct allotment of units; Greater interaction between verifier and operator; Batch identification; Radio on each machine</td>
<td>2,5</td>
<td>83,7</td>
</tr>
</tbody>
</table>

Figure 8. Unnecessary unit movements  
Source: The authors themselves

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

Figure 9. Repair estimate differs from survey  
Source: The authors themselves

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

Figure 10. Unit released with load capacity different from capacity required in booking.  
Source: The authors themselves

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

Figure 11. Released shipowner unit differs from booking  
Source: The authors themselves

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

Figure 12. Malfunctions not noticed during the survey  
Source: The authors themselves
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.

Table 1. Ranking of Potential Failure Modes

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

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.

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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.

REFERENCES


