

# **RESEARCH PROJECT REPORT**

## **Application of Statistical Process Control to Operational Events in a Dry Bulk Loading Process at a Distribution Center in Malaysia**

by

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Submitted to the MIT Malaysia Supply Chain Management Program in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN SUPPLY CHAIN MANAGEMENT

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### **ABSTRACT**

Companies increasingly seek the continuous improvement of their processes to reduce costs, improve quality, increase competitiveness, and seek excellence in the efficiency of their business. A successful technique that has evolved a lot over the years due to the consistent results achieved is the application of Statistical Process Control (SPC) to identify weaknesses and opportunities for improvement. This work uses statistical and quality tools to improve the productivity of the iron ore loading process at a dry bulk distribution center in Malaysia. The focus of the work are the operational stoppages that are considered intrinsic to the process, using the performance data from 2019, since the data from 2020 were contaminated by the special work models caused by the COVID-19 outbreak. This analysis conveys the events that influenced the variability of the process, being a statistical plan about which events and how to act to increase the system's productivity.

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Title: CEO, Malaysia Institute for Supply Chain Innovation

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# **1 Introduction**

In a world that is becoming increasingly globalized, companies need to act quickly to remain competitive and not lose market share, the quality and stability of processes have been determining factors in the permanence of companies in the segment in which they operate and conquer new markets.

To reduce costs and losses and become increasingly efficient companies, continuous improvement to increase productivity has been used by practically all companies.

Statistical Process Control (SPC) is one of the most effective tools in monitoring and detecting improvements in production processes, especially in logistical processes where the predictability that is the most relevant factor is only achieved with stable processes.

The objective of this work is to apply Statistical Process Control techniques in the intrinsic stoppages called the operational iron ore loading process in a dry bulk distribution center in Malaysia.

The study of the process of iron ore loading is located in Malaysia, in the state of Perak, in a maritime terminal that started operating in November 2014. The facilities consist of a deep-water port and five storage yards, where different types of iron ore can be mixed and customized according to the needs of steelmakers. Equipped with an import berth with the capacity to unload vessels of up to 400 thousand tons and an export berth capable of loading capesize vessels, the distribution center is a distribution point in Asia that maintains a constant stock of iron ore.

The method will be the analysis through a data collection collected in the year 2019, since the data of 2020 are contaminated by the special work models created on the account of the COVID-19 outbreak. Application of the techniques of Statistical Process Control were made with the Minitab software in order to statistically diagnose the process. After a detailed analysis of the parameters and graphs found, the work will present a statistical plan with the events to be worked on and how to act on these events to increase the productivity of the process making it more stable and efficient.

After this statistical diagnosis, this work should answer:

- What are the points of greatest loss of production in a standard bulk shipment?
- What should be the points of improvement to be worked on based on statistical data?
- Demystify points about operational losses that come from common sense, but are they not statistically critical?
- What are the statistical tools to be used to optimize the processes working on internal benchmarks?



**Figure 1 - Logistical time reduction between South America and Asia**

## **2 Literature Review**

In this chapter, the main theoretical references, tools, and definitions that were used during the development of this work will be presented and discussed. It also lays out the development and studies related to the techniques of Statistical Process Control in the last past years.

### **2.1 Total quality production**

There is no way to talk about Statistical Process Control without mentioning quality. Quality started in the Industrial Revolution, with the design of Ford's serial production lines, but in a discreet way and without taking the customer's satisfaction into account.

Quality has become one of the most important consumer decision-making factors in the selection of competing products and services. The phenomenon is general, regardless of whether the consumer is an individual, an industrial organization, a retail store, or a military defense program. Consequently, understanding and improving quality is a key factor that leads to success, growth, and a better competitive position for a business. The best quality and the successful use of quality as an integral part of the company's overall strategy produce a substantial return on investment.

(MONTGOMERY, 2004, p. 1)

“Permanent control of processes is a basic condition for maintaining the quality of goods and services. There is no single and universal definition of quality in the literature”. (COSTA, EPPRECHT and CARPINETTI, 2005, p. 15)

According to Costa, Epprecht and Carpinetti (2005, p. 15), quality gurus defined quality as suitability for use. Deming in 2000 believes that, quality means meeting and, if possible, exceeding consumer's expectations. In addition, Crosby in 1995 established the idea that quality means meeting specifications. However, in 1999, Taguchi proposed the meaning, production, use and disposal of a product always causes damage to society, and the lower the damage, the better the quality of the product. According to Prieto and Carvalho (2005), quality is the result of a planning effort, which involves the participation of everyone in the organization, from the board of directors to the lowest level of operation, it is not restricted to actions of a single organizational level nor by the effort of a single productive area or sector.

Quality, since its creation, has gone through three important phases: inspection, statistical control and total quality.

## **2.2 Statistical control of production**

To improve inspection and quality techniques, American Walter Andrew Shewart; the statistical techniques of quality control, emerged. Due to the second world war, Montgomery (2004) stated that the experiences lived in the war and post-war, it became clear that statistical techniques were necessary to control and improve the quality of products. In the United States of America (USA), these statistical techniques were implemented by its suppliers and this spreads the new control method around the world.

After the defeat in World War II, Japan was faced with the reality of being completely destroyed and needing to start its reconstruction process. With that, Deming, an American and quality guru, was invited by the Japanese Union of Scientists and Engineers (JUSE), to give lectures on Statistical Process Control (SPC) and PDCA Cycle (Plan, Do, Check and Action), which was also known as the Quality Deming Cycle, Deming also lectured on Quality Management, targeting entrepreneurs, engineers, and industrialists. (Longo,1996).

According to Ishikawa (1986), to show gratitude for the services provided to Japan by Dr. EW Deming, who conducted several courses and lectures. In order to eternalize the kindness of Deming who gave the copyright of his lectures to Japanese industries, JUSE, the Deming Quality Award was instituted to those who contributed significantly to the dissemination of Statistical Quality Control techniques and to companies where the Statistical Quality Control was conducted in an exemplary manner.

According to Montgomery (2004), Dr. Deming used a 14-point philosophy for management:

1. Create consistent actions focused on improving products and services. Maintain commitment to improving the project and product performance. Investments in research, development and innovation will bring long-term returns for the organization.

2. Establish a firmer philosophy of poor quality in the process. The cost of rework will have the same value as the cost of production, so the product will have the production value doubled, when rework is necessary, sometimes making the process unfeasible.
3. Do not rely on mass inspection to “control” the quality, it can be flawed when dealing with robust defects, and is ineffective in reducing production costs, as only it will only detect anomalies after the product is produced, and it is not possible to redeem the capital spent on the production of the non-compliant product. Inspection typically takes place very late in the process, is expensive and, in general, ineffective. Quality results from the prevention of defective items through process improvement, not inspection.
4. Do not reward suppliers for doing business based on price alone, but also consider quality. The price is only the measure used to measure the supplier's product. Buy also based on quality and innovative process improvement techniques that your supplier applies to your product, in order to establish the capacity of your process.
5. Focus on continuous improvement. Always seek continuous improvement of your production system. Involve all company employees in these activities and make use of statistical methods.
6. Put current training methods into practice and train all employees. Everyone must obtain technical knowledge about the task they will perform, as well as in modern methods of improving quality and productivity. The training should encourage employees to seek improvements for their process and for the company.
7. Put modern supervision methods into practice. Supervision does not ask to be focused only on the control and surveillance of its employees but, must focus on helping employees to seek improvements to the system in which they work. The main objective of supervision should be to improve the work system and the product, together with its employees.
8. Encourage employees to pass on information about the process, in many organizations, the economic loss related to the lack of communication between employees and management due to fear is great, only management can disinhibit employees.

9. Eliminate the company's industry separations. Teamwork between different units of the organization is essential for a continuous improvement of quality and of processes and services to take place.

10. Discard goal communication forms that contain intangible targets, slogans, and complex numbers for employees. Objectives such as “zero defects” will be ineffective unless preparation and an action plan for consolidating and applying the same are not carried out. In fact, such slogans and programs are demotivating. Work to improve the system and provide clear and objective information about it.

11. Eliminate numerical quotas and unsubstantiated work patterns. Establish your own work methodology. Work patterns are, in general, symptoms of management's inability to understand the work process and provide an effective management system focused on improving this process.

12. Remove barriers that discourage employees from doing their jobs. The manager must establish a bond of mutual assistance with his employees in order to recognize the process improvements passed on by them. Sometimes a great idea may arise from the operating processes, as they deal with the situation on a daily basis and are often the first to realize the sources of the anomalies. The workforce is an important player in the business, not just an opponent in collective bargaining.

13. Institute a permanent training and education program for all employees. Education in simple but powerful statistical techniques should be mandatory for all employees. The use of the basic SPC tools for problem solving, particularly the control chart, should become common in the company and used by all involved in the process. As these charts spread across sectors and employees understand their use, these employees are more likely to look for the causes of poor quality and identify improvements in the process. Education is a way to make everyone a partner in the quality improvement process.

14. Create a structure at the highest level of management that will vigorously defend the first 13 points.

Through these 14 points reported by Deming, it is clear that there is a strong focus on the involvement of process employees and requires more attitudes from process supervisors to better support operational levels and listen to their opinions and suggestions, and not just visually monitor the process, this also emphasizes the more direct participation of senior management in providing conditions for the system to work better and more effectively.

According to Oliveira, et al (2004), inspection control was becoming unfeasible, due to the increased demand for products required by the market, where it was overloading the production lines, with which statistical techniques were implemented in order to improve and streamline inspection on production lines. Through this technique, products on the production line were selected at random to be inspected, in such a way that this sample lot represented the quality of the entire lot produced.

## **2.3 Statistical process control (SPC)**

In the sense of this continuous improvement, several tools have been created so that organizations can easily see what customers expect from them and how they can improve internally to meet those needs. The main objective discussed in this work, is to discuss one of the tools used, Statistical Process Control.

Statistical Process Control is a preventive tool that aims to develop and apply the statistical method within a process, helping its apprehension. This apprehension is done by analyzing trends of significant variations and using method and statistical data.

The main objective of SPC is to stabilize the process by reducing its variation, ensuring an improvement and a constant maintenance of quality. In this way, compliance is ensured, meeting the needs of internal and external customers (GOMES, 2010).

Among many of its uses, this tool helps to prevent defects in the process, helps to reduce costs and promotes better management of product quality.

In many cases, by statistically analyzing the process, it is possible to verify evidence that it is not occurring properly due to some failure regarding the maintenance of instruments. There



are factors within the process that generate variations in the quality of the product. A finding like this can avoid unnecessary financial investments and stoppages due to less severe and less frequent maintenance.

Because it is a preventive tool, many problems in the process are still solved in a low complexity, providing less financial expense and time to solve it. (GOMES, 2010)

Through Statistical Process Control, it is possible to easily visualize the conformity of the product according to a determined situation of the process inputs. In other words, you can see the influence of each of the entries on the final result and it is possible to configure them for better product quality.

In addition to all of these benefits, CEP adds knowledge of the process and the most critical points related to it, facilitating the visualization of possibilities for improvements.

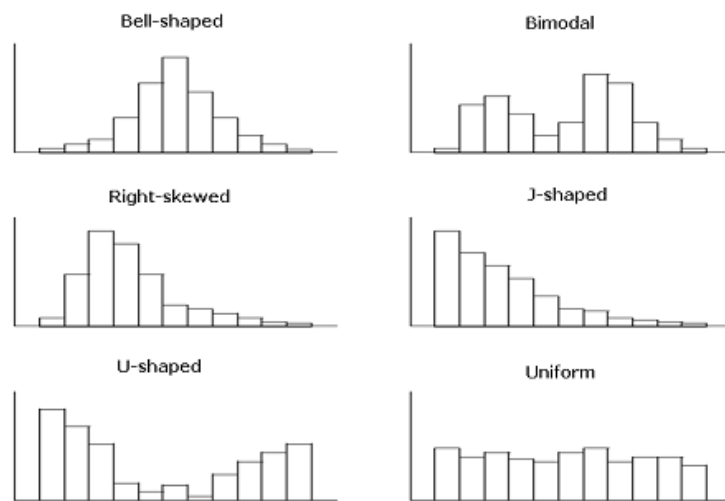
## **2.4 The SPC Tools**

According to Ishikawa (1986), seven tools were created called the 7 Instruments for Quality, where they will be understood, analyzed and used by all levels of the company. Thus, 95% of the existing problems can be solved with the help of these 7 instruments of the QC, which are:

- 1- Histogram
- 2- Cause and Effect Diagram
- 3- Flow Chart Check Sheet verification
- 4- Defect Concentration Diagram
- 5- Pareto diagram
- 6- Scatter Diagram
- 7- Control charts

### 2.4.1 Histogram

"Histogram is a statistical tool that provides the frequency of occurrence of a given value or class of values in a group of data". (CARBURON, MORELES 2006. p 2). A histogram can have different shapes indicating the behavior of the data.

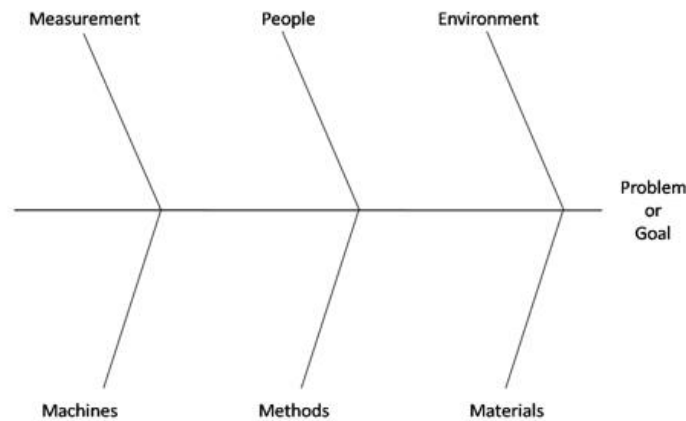


**Figure 2 - Exemplification of Histogram by shape**

### 2.4.2 Cause and Effect Diagram

Cause and Effect Diagram, according to Carburon, Morales (2006), is a tool for analyzing technical factors that can be used to correlate the results of the process and their failures, which can interfere with the desired result.

According to Montgomery (2004), the cause-and-effect diagram is an essential tool in the application of SPC, because if applied correctly and in detail, it allows to identify, locate, propose solutions and repair problems without centralizing the fault of the same.



**Figure 3 - Exemplification of Cause-and-Effect Diagram**

### **2.4.3 Flowcharts and Check Sheet**

According to Juran (1992), Flowcharts is a representation of the stages of a process through graphic means. As the assembly of a company's flowchart involves the commitment of a multifunctional team, the benefits obtained in the process are greater.

Montgomery (2004) check sheets or control sheets are very useful for collecting data in the process and registering process histories. These must be well designed and filled in, to avoid future problems regarding the application of the data obtained in the subsequent tools.

### **2.4.4 Defect Concentration Diagram**

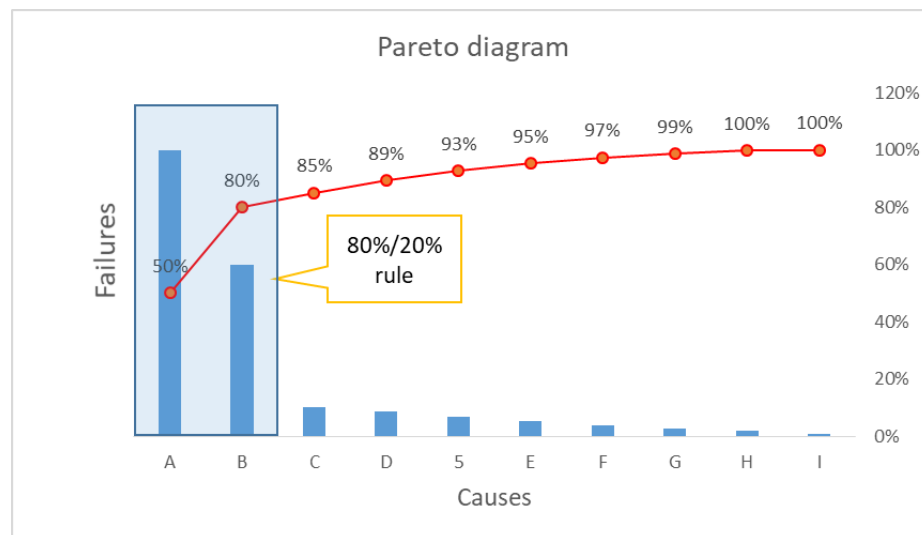
Montgomery (2004), the Defect Concentration Diagram seeks to locate the defects and determine whether they offer any information to aid in the analysis of the problem solution, identifying whether there is a greater concentration in the occurrence of the anomaly in a certain area of the product or process.

### **2.4.5 Pareto Diagram**

According to Cortivo (2005), the diagram is a creation of Italian Vilfredo Pareto, who was a scholar of the distribution of wealth of his time, when at the time he discovered that there was a great social inequality, where few had great wealth, and many had nothing. Through this discovery,

Juran, after having the same perception, that this relationship of inequality was also occurring with the quality problems, then applied the Pareto diagram to assist him in solving the problems. The Pareto diagram consists of a graphical representation of data, in decreasing order of frequency, and through this information you can centralize improvement efforts at the points where you will obtain the greatest gains. It is concluded that the Pareto diagram aims to indicate the main problems of the process graphically.

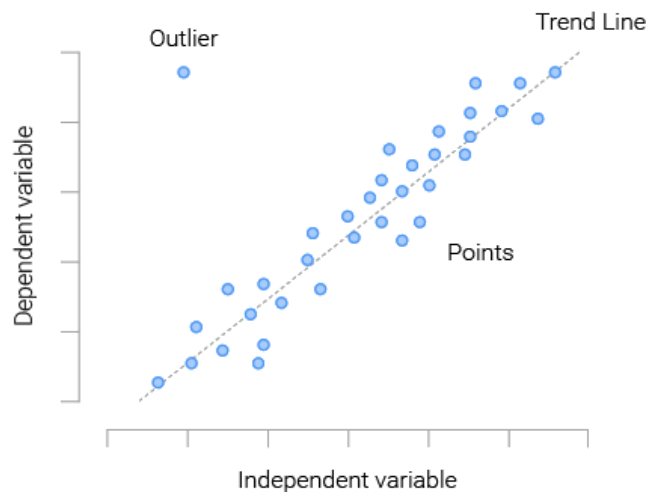
Vilfredo Pareto was a 19th century Italian economist who invented the diagram based on the distribution of wealth in society age, where he concluded that 20% of the population (few and vital) held 80% of the wealth, while the rest of the population (many and trivial) held only 20%. The relationship is also known as the 80/20 rule. The Pareto Principle has become a common rule in the business world where 80% of problems are concentrated in 20% or less of the causes.



**Figure 4 - Exemplification of Pareto Diagram**

#### 2.4.6 Scatter Diagram

Montgomery (2004), the dispersion diagram is used to identify potential relationships between two variables, that is, it is a useful tool in the identification of potential relationships.



**Figure 5 - Exemplification of Scatter Diagram**

#### **2.4.7 Control charts**

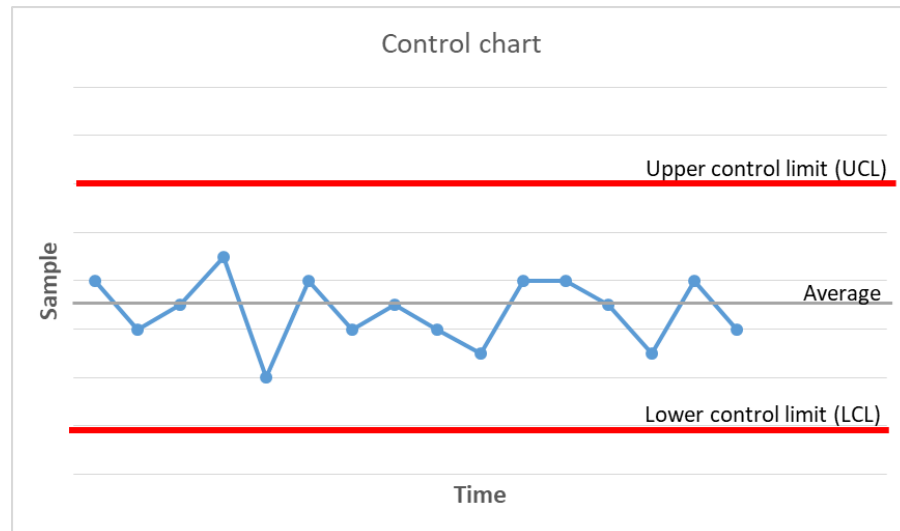
The Control Charts, is a graphical comparison of the performance of a process with a control limit, obtaining the result by distributing the points on the graph according to random patterns and within the specification limits. Then comes the analysis as to the status of the process under control, which is when the graph with the points randomly distributed. Subsequently, when the status of the process is out of control, which is when the points exceed the control limits of the graph or they are not randomly distributed.

In order to identify the occurrence of special causes to apply a possible solution, a widely used tool is the control charts or graphs. If the process is under control, this chart is used to propose improvements. In case the process is already under control, the control charts are used for the present and future analysis (GOMES, 2010).

Control charts are a form of continuous monitoring of process variability. Its main objective is to detect abnormal variations so that their possible causes are raised and studied, reaching solutions that eliminate them and prevent them from happening again. The control charts are formed by plotted values collected in the process during a certain time (day-day, hour-hour, minute-minute).

In practice, a responsible person plans and assembles a data collection plan and makes measurements in the process according to that plan. In this plan, the collection frequency, the number of pieces and even how the pieces should be chosen for measurement are defined.

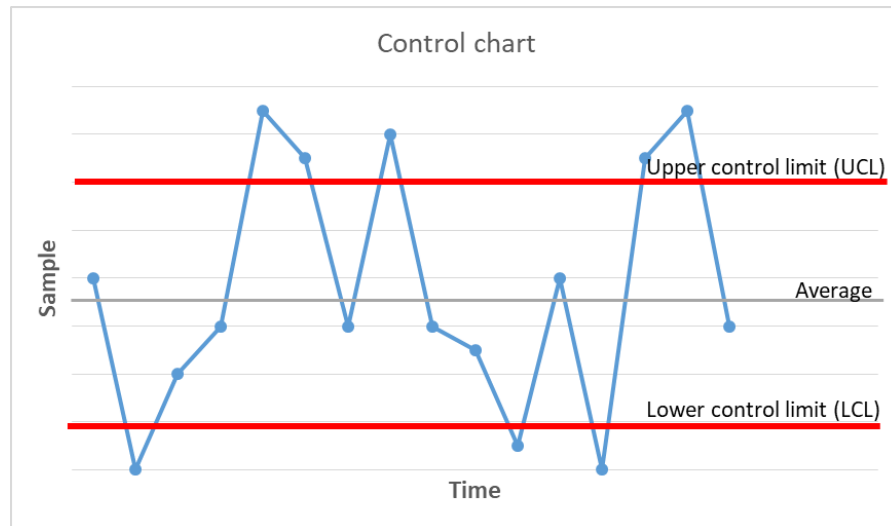
One of the types of control chart is by attribute, that is, the observations are classified by attributes, containing proportion of non-conforming pieces, number of approved pieces, etc.



**Figure 6 - Example of control chart with the process under control**

Another example of a control chart is the one formed by variables, that is, the plotted data are values measured numerically in some way. This type of control chart usually shows more characteristics of the process than the previous graph. In these graphs, the values observed in each sample can be placed. The averages of the results obtained in each of the samples, the proportion of defective parts within a sample or even the amplitude observed within it. The values are placed in temporal order, where the horizontal axis represents each sample collected and the vertical axis the values that these samples represent.

In the control charts there is also a central line and two others called control limits. From these lines, the decision rule is simple and visual: points arranged above the upper control limit or below the lower control limit indicate that the process is out of control.



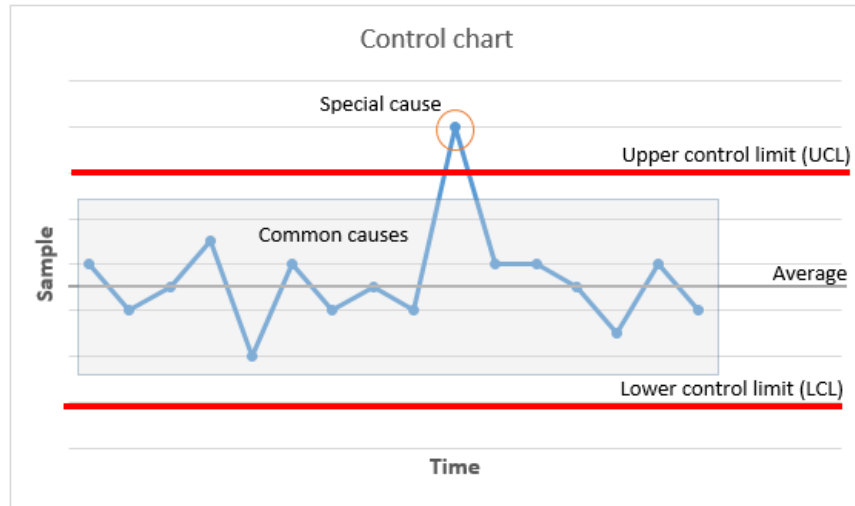
**Figure 7 - Example of control chart with the process out of control**

#### **2.4.7.1 Common variations and special variations**

Within a process, there are 2 types of causes of variations, those caused by so-called common causes or by special causes. The first type is natural to all processes, that is, it is the natural degree of variation that every process presents. These are the so-called common causes. Every process, however stable it may be, has a natural variation. These variations are the sum of the causes of inherent variability (CARPINETTI, 1998).

The special variations are those caused by some factor that is not natural to the process, be it a deregulation in the machine, a problem in the tool or even an action by the operator. This is the type of cause that seeks to control or even extinguish the process using the CEP. Special causes are due to unusual occurrences, occasionally present in the process (RIBEIRO, 2012).

Based on these variations, the process is classified as in or out of control.



**Figure 8 - Example of control chart cause variation**

#### 2.4.7.2 Calculation of control chart limits

As in the analyzed processes, thousands of pieces are output per hour and the cost of each observation is low, it is convenient to measure more than one piece in each sample. In view of this, the calculations below refer to samples with  $n > 1$ .

The parameters of a control chart are calculated as shown below (GOMES, 2010). In calculating the parameters of the control graph, we start with, given by equation 1:

$$\bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n}$$

**Equation 1 - Calculation of the mean, Source: GOMES, 2010**

Then, based on the assumption that the sample is large enough for the sample mean to generate a normal distribution.

If  $m$  samples of  $n$  units each sample, we have the best estimator of the process average ( $\mu$ ), the central line of the graph of, shown in equation 2:

$$LC = \bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_m}{m}$$

**Equation 2 - Calculation of the central limit, Source: GOMES, 2010**



To estimate the standard deviation, the amplitude R is used. Thus, the amplitude of each sample is given by equation 3.

$$R = X_{\text{máx}} - X_{\text{mín}}$$

**Equation 3 - Amplitude calculation, Source: GOMES, 2010**

From this, the central line (LC) or average of the amplitudes is given by equation 4:

$$\overline{R} = \frac{R_1 + R_2 + \dots + R_m}{m}$$

**Equation 4 - Calculation of the average amplitudes, Source: GOMES, 2010**

The second step of calculations is to determine the control limits. From the unbiased estimator of the standard deviation given by the equation below, we have all the tools necessary for calculating the limits.

$$\hat{\sigma} = \frac{\overline{R}}{d_2}$$

**Equation 5 - Calculation of the standard deviation estimator, Source: GOMES, 2010**

$$LSC = \mu_{\overline{X}} + 3 \frac{\sigma}{\sqrt{n}} = \overline{\overline{X}} + 3 \frac{\overline{R}}{d_2 \sqrt{n}}$$

**Equation 6 - Calculation of the upper limit of the mean graph, Source: GOMES, 2010**

$$LIC = \mu_{\overline{X}} - 3 \frac{\sigma}{\sqrt{n}} = \overline{\overline{X}} - 3 \frac{\overline{R}}{d_2 \sqrt{n}}$$

**Equation 7 - Calculation of the lower limit of the mean graph, Source: GOMES, 2010**

On the other hand, the limits of the graph of R are given by equations 8 and 9:

$$LSC = \overline{R} + 3 \hat{\sigma}_R = \overline{R} + 3 d_3 \frac{\overline{R}}{d_2}$$

**Equation 8 - Calculation of the amplitude graph upper limit, Source: GOMES, 2010**

$$LIC = \overline{R} - 3 \hat{\sigma}_R = \overline{R} - 3 d_3 \frac{\overline{R}}{d_2}$$

**Equation 9 - Calculation of the amplitude graph lower limit, Source: GOMES, 2010**

Where d2 and d3 are constants that depend on the sample size, as shown in table 1.

SAMPLE	d <sub>2</sub>	d <sub>3</sub>	SAMPLE	d <sub>2</sub>	d <sub>3</sub>
2	1,128	0,953	14	3,407	0,763
3	1,693	0,888	15	3,472	0,756
4	2,059	0,88	16	3,532	0,75
5	2,326	0,864	17	3,588	0,744
6	2,534	0,848	18	3,64	0,739
7	2,704	0,833	19	3,689	0,734
8	2,847	0,82	20	3,735	0,729
9	2,97	0,808	21	3,778	0,724
10	3,078	0,797	22	3,819	0,72
11	3,173	0,787	23	3,858	0,716
12	3,258	0,778	24	3,819	0,712
13	3,336	0,77	25	3,931	0,708

**Table 1 - Constants for calculating the limits, Source: GOMES, 2010**

## 2.5 Normal Distribution Curve

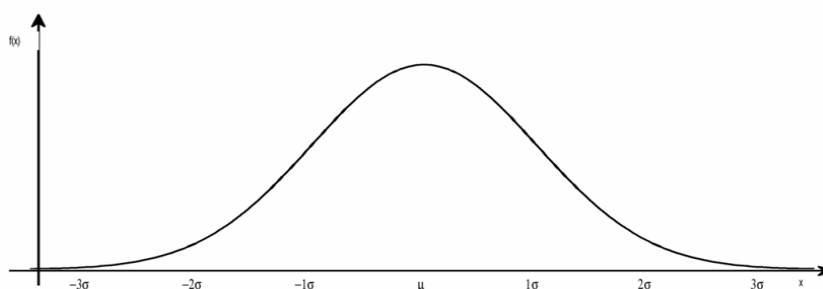
In the area of probability and statistics, normal distribution is a form of distribution that can be used to model various natural phenomena. In many cases, factors and process results follow a distribution that tends to be Normal.

The function that defines the normal distribution is defined in equation 1.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

**Equation 10 - Normal distribution function, Source: GOMES, 2010**

$\sigma$  represents the standard deviation of the sample and  $\mu$  represents the sample mean. The shape of the Normal curve is similar to the graph below:



**Figure 9 - Generic normal distribution curve, Source: GOMES, 2010**

To determine whether the data does not follow a normal distribution, compare the p-value with the level of significance. Generally, a significance level (denoted as  $\alpha$  or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that the data does not follow the normal distribution when they actually follow it.

**P value  $\leq \alpha$ : Data do not follow a normal distribution (Reject H0)**

If the p-value is less than or equal to the level of significance, you must reject the null hypothesis and conclude that your data does not follow the normal distribution.

**P value  $> \alpha$ : It is not possible to conclude that the data does not follow a normal distribution (must not reject H0)**

If the p-value is greater than the significance level, you should not reject the null hypothesis. There is insufficient evidence to conclude that the data does not follow a normal distribution.

## 2.6 Cp and Cpk

The capability of a process is measured by the Cp index, the ratio of the difference between the specification limits and the process limits, as shown in equation 11.

$$C_p = \frac{LSE - LIE}{LSNT - LINT} = \frac{LSE - LIE}{\mu + 3\sigma - (\mu - 3\sigma)} = \frac{LSE - LIE}{6\sigma}$$

**Equation 11 - Calculation of process capability, Source: GOMES, 2010**

Since the Cp index does not indicate a lack of centrality, there is a need to also use the Cpk index for a more precise analysis.

$$C_{pk} = \min\left(\frac{LSE - \mu}{3\sigma}, \frac{\mu - LIE}{3\sigma}\right)$$

**Equation 12 - Cpk Calculation, Source: GOMES, 2010**

In general, the usefulness of Cp is to measure the potential capabilities of the process while the Cpk provides the current capabilities of the process. In other words, when the special causes of variation of a process are eliminated and it is centered on  $\mu$ , its capability is given by Cp.

A practical analysis of the Cp and Cpk values can be done as follows (MEDEIROS, 2013):

- Cp and Cpk > 1.33: process capable of +/- 4 standard deviations and a maximum of 26 pieces out of tolerance for every 1 million pieces produced.
- Cp and Cpk > 1.00 and < 1.33: process capable of +/- 3 standard deviations and a maximum of 2700 pieces out of tolerance for every 1 million pieces produced.
- Cp and Cpk < 1: process capable of +/- 3 standard deviations and more than 2700 parts out of tolerance for every 1 million parts produced.

## **2.7 Pp e Ppk**

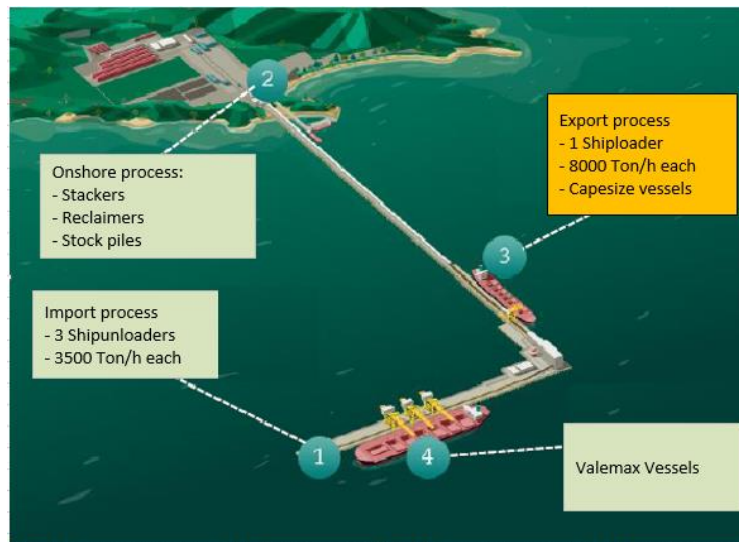
Proposed by Herman in 1989, both indices are used to measure the performance of a process. If the performance of a process is high, that is, if there is little variation, the capability indices tend to approximate the performance indices. The opposite also occurs, numerically indicating the existence of special causes of variation (MEDEIROS, 2013).

The analysis of the process capability allows the prediction of tolerances that will be used in projects or passed on to customers, helps in the performance specifications of new equipment, helps in planning the order of processes so that tolerances are maintained and, mainly, reduces the variation of a production process (LOUZADA et al., 2013).

### 3 Data analysis

#### 3.1 Process

The process studied will be that of loading vessels where a ship loader called CN1 receives material reclaimed from ER01 or ER04 reclaimer machine at the blending piles of patios D and E to load Capesizes vessels. The loading capacity of the CN01 is 8000Ton/h as well as the reclaiming capacity of each of the reclaimers. Statistically and focused on the intrinsic process shutdowns known as operational shutdowns, the study analyzes whether the process is capable of fulfilling the performance assumptions previously established and the relationship of gains with other process factors. The operating mode of the process is 7 days a week 24 hours a day, with no planned idleness and the working time is divided in four operation teams in shifts called Shift 1, Shift 2, Shift 3, and Shift 4.



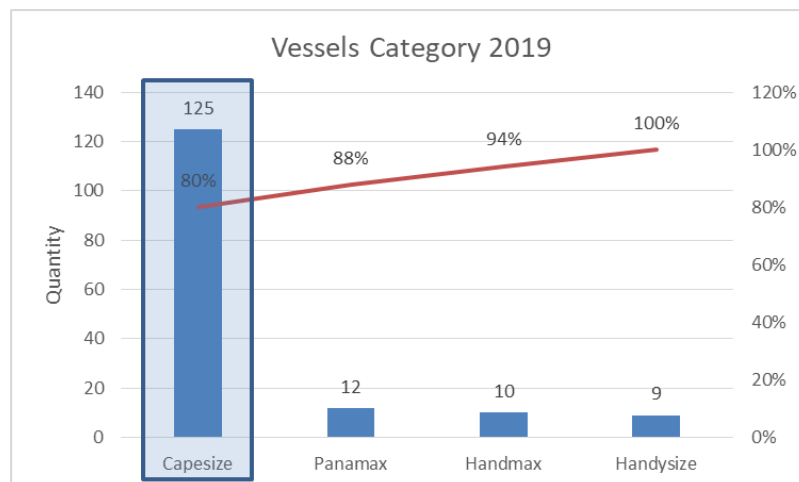
**Figure 10 - Malaysia Distribution Center plant**



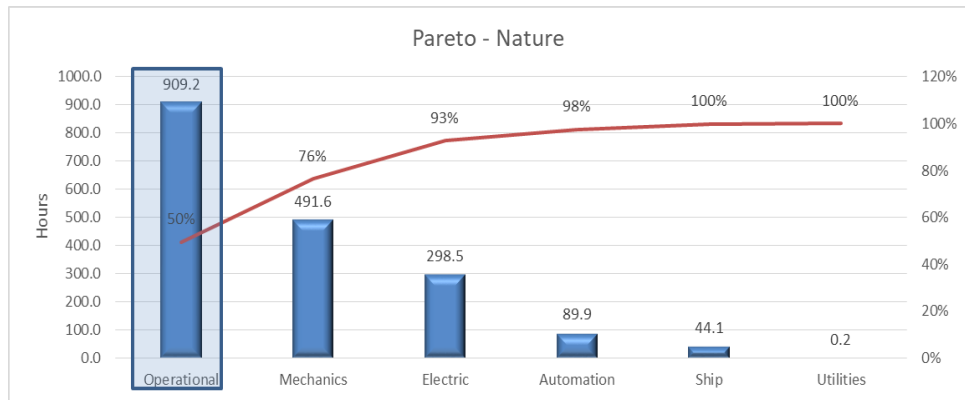
**Figure 11 – Origin machines (ER01 and ER04)**

### 3.2 Losses stratification

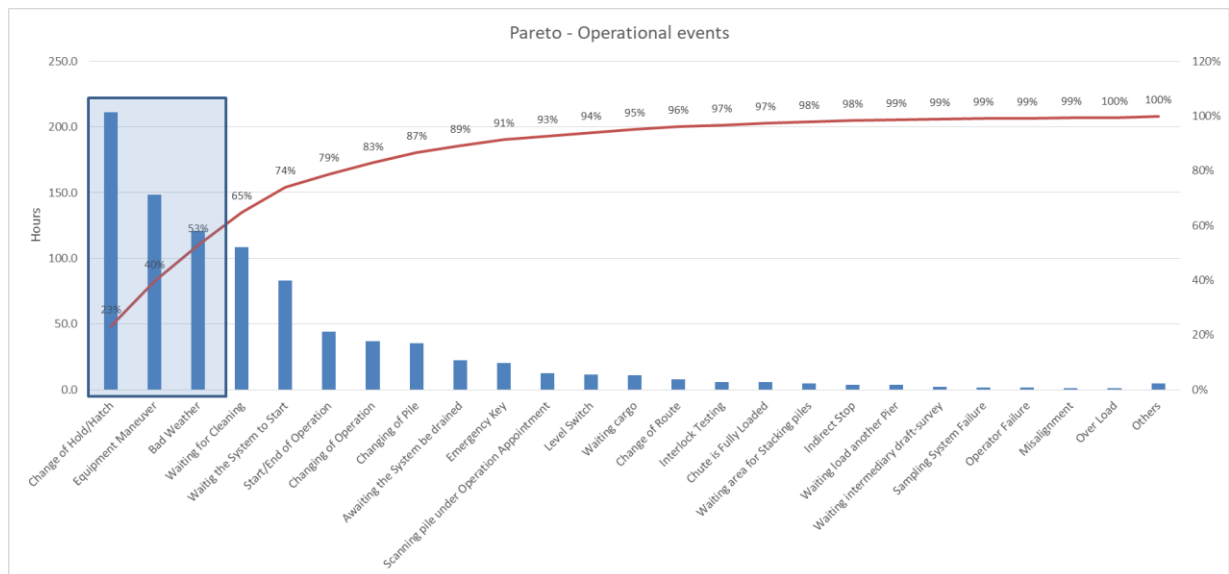
The study focuses only on Capesize vessels as they are the standard model of the terminal and represent 80% of the vessels, the other categories are considered exceptions.



**Figure 12 - Terminal fleet in 2019**



**Figure 13 - Pareto of faults by modality for Capesizes**



**Figure 14 - Pareto of shutdowns due to operational events**

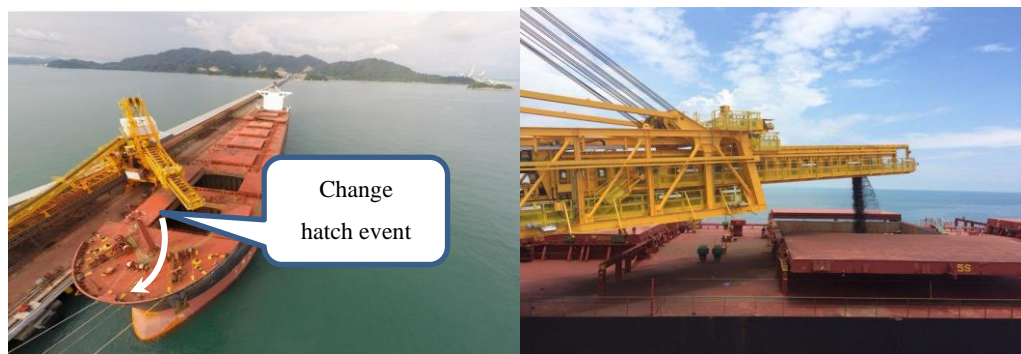
### 3.3 Main events

Operational event	%
Change of Hold/Hatch	23%
Equipment Maneuver	40%
Bad Weather	53%
Waiting for Cleaning	65%
Waitig the System to Start	74%
Start/End of Operation	79%
Changing of Operation	83%

**Table 3 - Main operational shutdowns of the process from Pareto**

### 3.3.1 Change of Hold/Hatch

All vessels have a loading sequence created previously by the vessel's command and validated with the port's programming department that determines the quantity that will be loaded in each hatch, known as the loading plan. This sequence is very important as it ensures that the loading will meet the safety limits of the vessel's structure and port equipment. After reaching the volume determined in each step of the sequence, it is necessary to paralyze the system so that the loader moves to the next hatch without dropping cargo on the ship's deck, this stoppage is called "Change of hold/hatch".

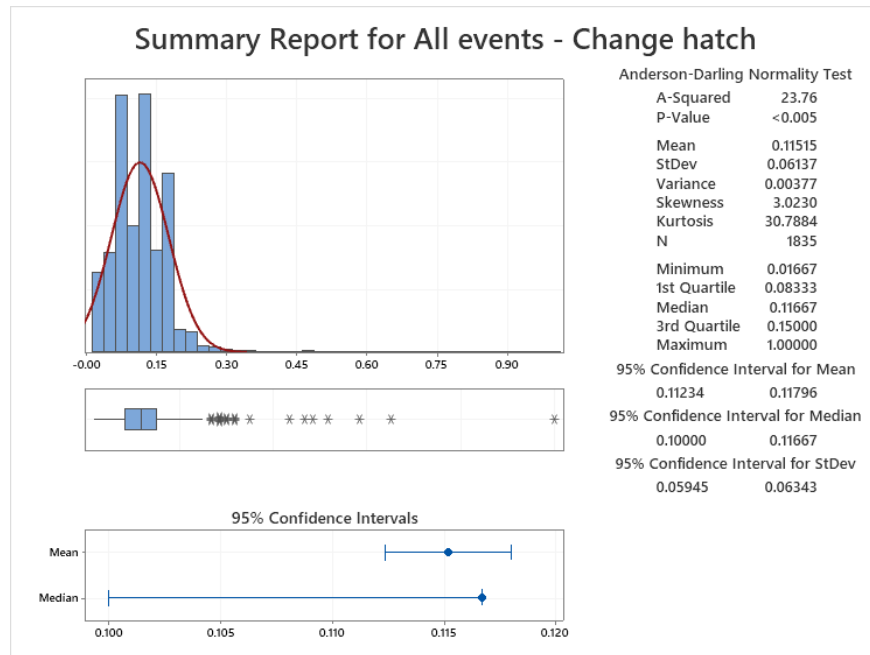


**Figure 15 – Change hold/hatch event**

According to the loading sequence defined by the vessel, there will be a big difference between the times of hatch changes, which can be of adjacent hatches or can be between the hatches of the extremities of the vessel, therefore the total time of change of hatch for each vessel Capesize will be used to define the behavior of the stoppage.

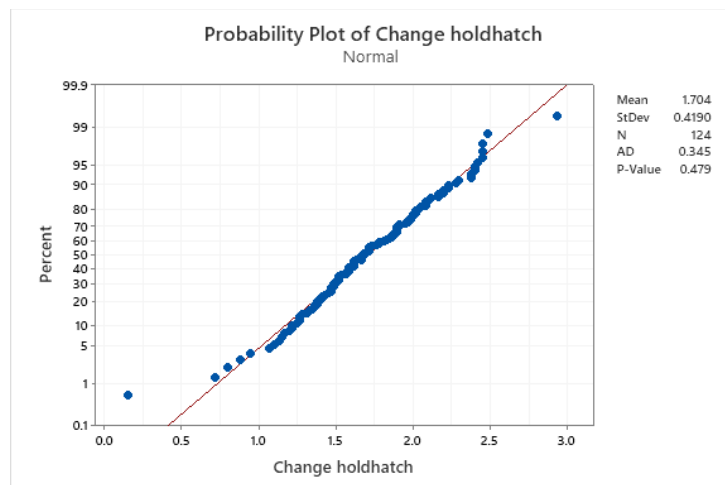




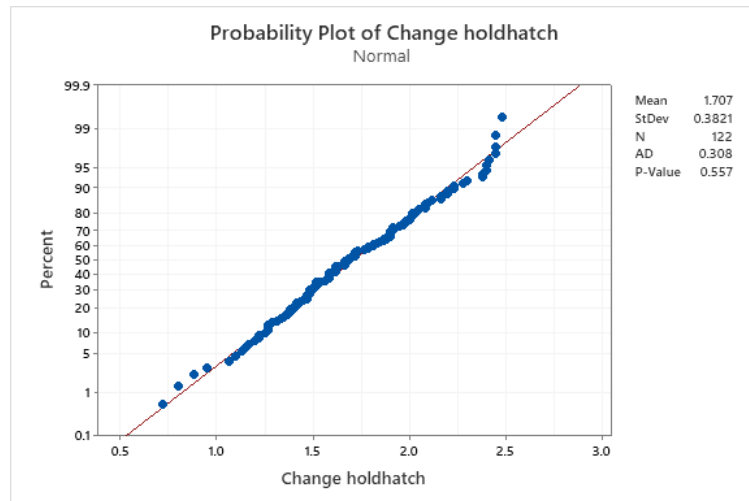


**Figure 18 - Statistical summary for all Change hold/hatch events in 2019**

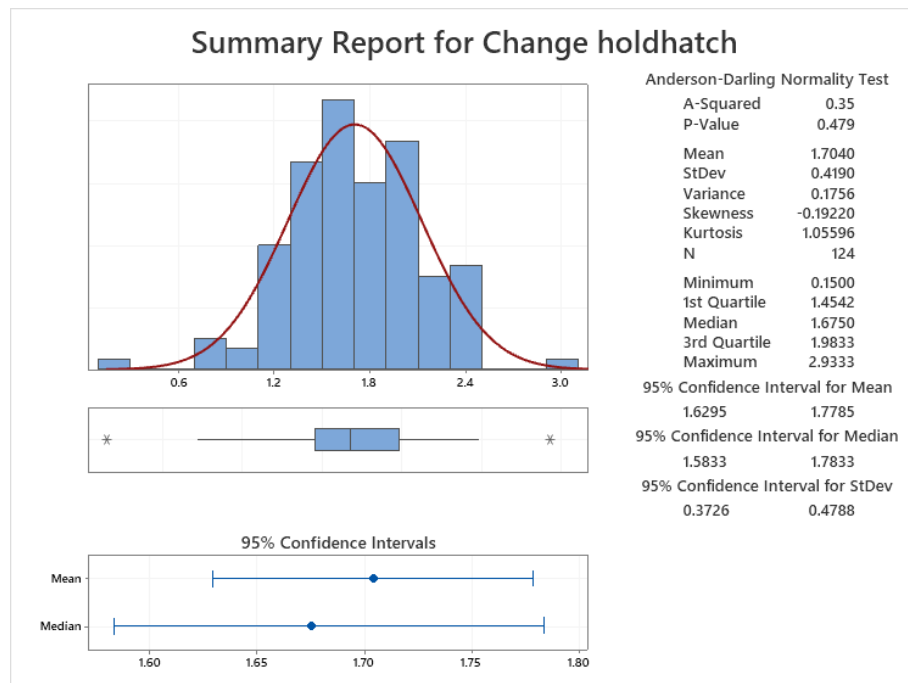
Normality test with and without special causes (Figure 18 and 19), both with P-Value above 0.05 showing that the distribution can be analyzed as normal.



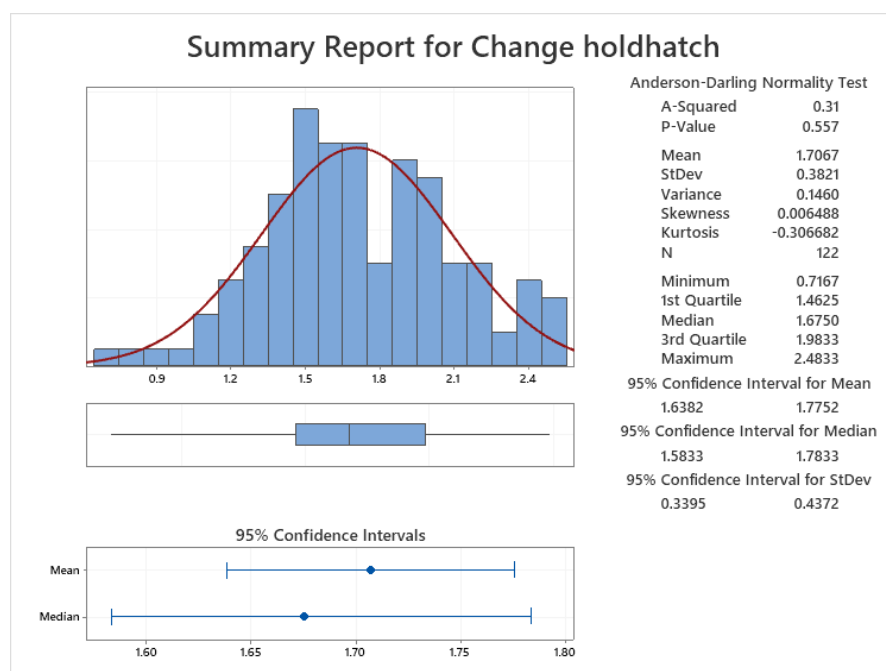
**Figure 19 - Distribution curve with special causes**



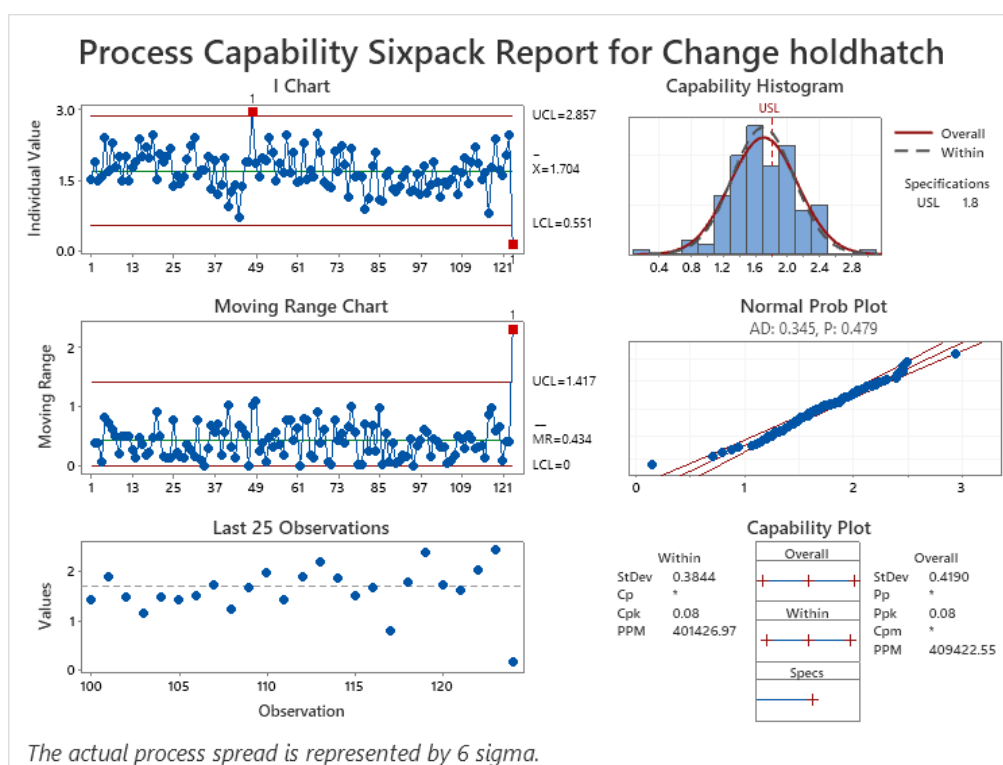
**Figure 20 - Distribution curve without special causes**



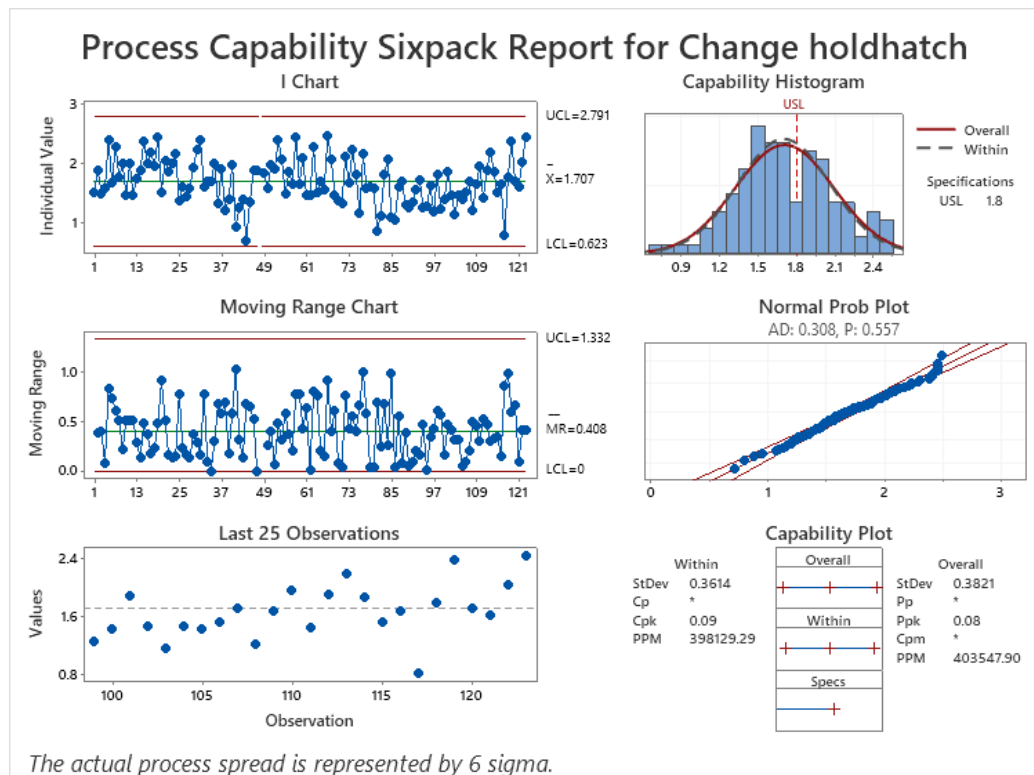
**Figure 21 - Summary analysis of the Change Hold/Hatch event with special cases**



**Figure 22 - Summary analysis of the Change Hold/Hatch event without special causes**



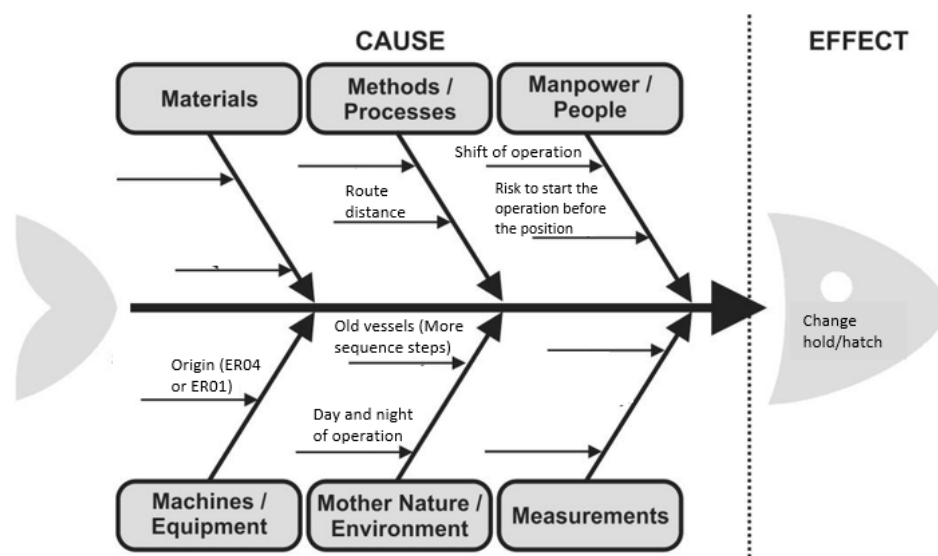
**Figure 23 - Capability analysis and control charts with special causes**



**Figure 24 - Capability analysis and control charts without special causes**

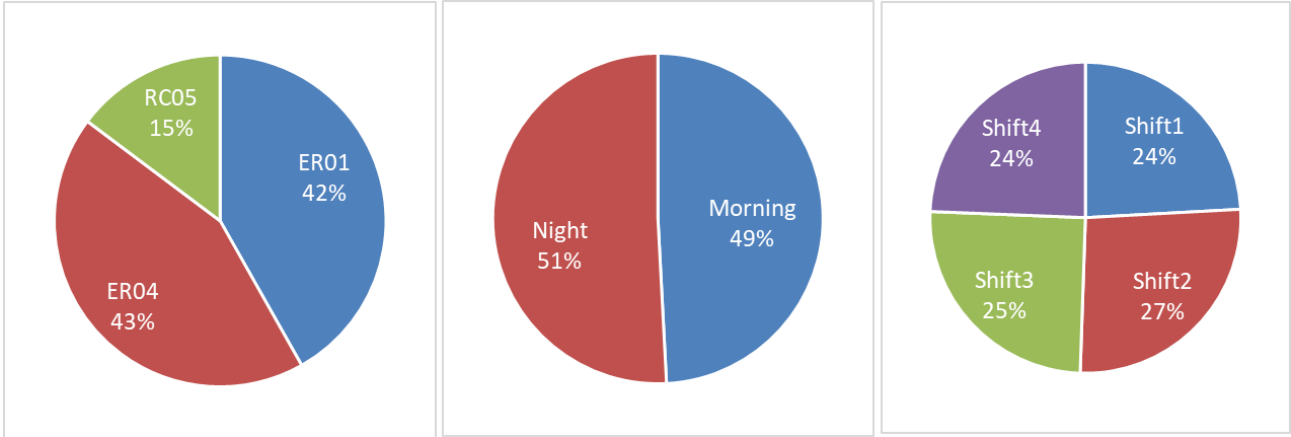
The process is under statistical control, but its upper limit is very far from the specification limit defined in the time planning for loading vessels, very low CPK and PPK show that in the long and short term the process is not capable.

The Ishikawa diagram was then used with the team in an attempt to check for possible causes of failure to reach the previously measured standard time.

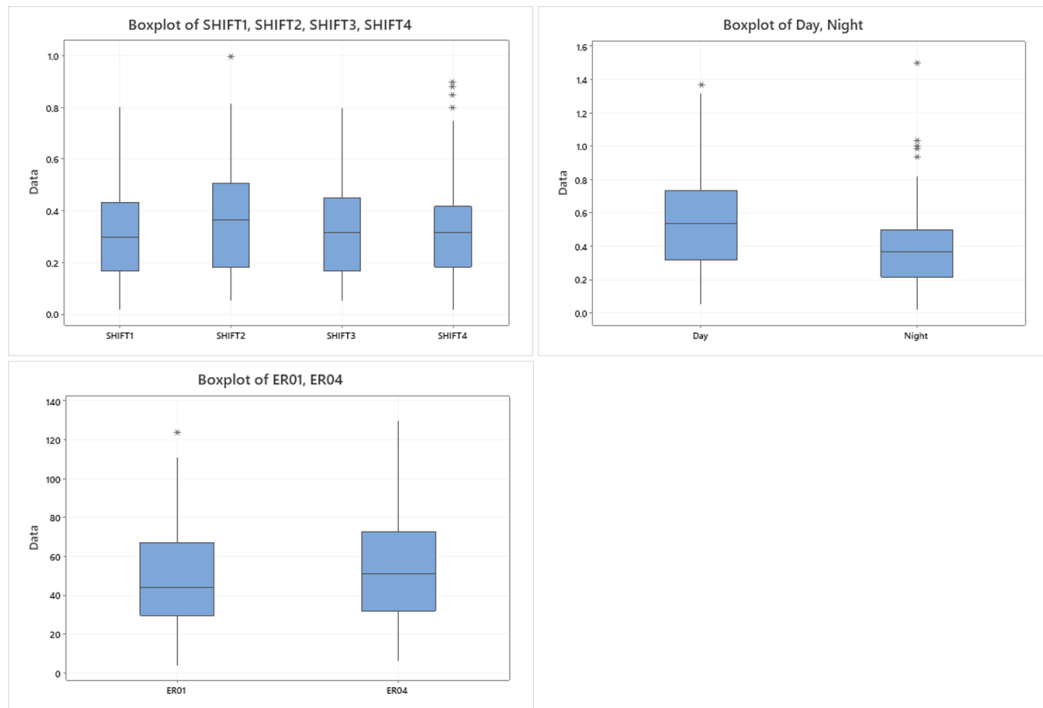


**Figure 25 - Ishikawa diagram for Change Hold/Hatch**

Statistical analyzes were carried out and it shows that there are some significant differences between the factors raised by the team regarding the possible causes of the long hold change time. In figure 26 and 27 we have the performance data during the night (Hour), during the day (Hour), per shift / day (Hour) and per machine / vessel (Min).



**Figure 26 - Percentage of stratified factors**



**Figure 27 - Boxplot of stratified factors**

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
SHIFT1	157	3	0.3100	0.0139	0.1747	0.0167	0.1667	0.3000	0.4333	0.8000
SHIFT2	149	1	0.3674	0.0173	0.2114	0.0500	0.1833	0.3667	0.5083	1.0000
SHIFT3	151	5	0.3306	0.0149	0.1825	0.0500	0.1667	0.3167	0.4500	0.8000
SHIFT4	153	0	0.3365	0.0158	0.1953	0.0167	0.1833	0.3167	0.4167	0.9000
Day	167	12	0.5536	0.0253	0.3266	0.0500	0.3167	0.5333	0.7333	1.3667
Night	279	0	0.3849	0.0129	0.2161	0.0167	0.2167	0.3667	0.5000	1.5000
ER01	114	1	48.79	2.42	25.87	4.00	29.75	44.00	67.25	123.98
ER04	110	0	53.70	2.72	28.49	6.00	32.00	51.00	73.00	130.00
RC05	46	0	43.65	5.90	39.99	1.00	11.75	23.00	74.00	131.00

**Table 6 – Statistical analysis summary of stratified factors**



**Figure 28 - Comparison of average and capability (Mean in hours)**

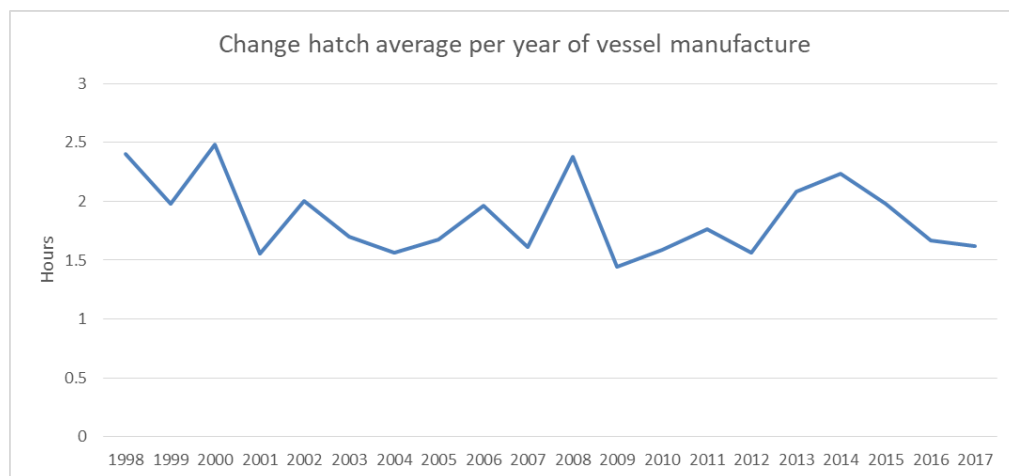
In addition to the diverse relationships between equipment, teams and the environment during the hatch change, the long distance between the port and the yard means that the calculation between the stoppage of the operation for the beginning of the CN movement and the return of operation that can be started before the CN is fully positioned in the hatch is risky, even after the measurements and time parameterization, since there is no automation in this synchronization. The material to go from the yard to the CN takes 12min to 15min, depending on the position of the material on the patio. This calculation is done by people and the safety time can vary according to the experience of the employees, causing losses for the system.





**Figure 29 – Distance from piles to Vessel**

The year of manufacture of the vessels with its construction differences does not influence the performance of the terminal, with losses occurring in old and new vessels.

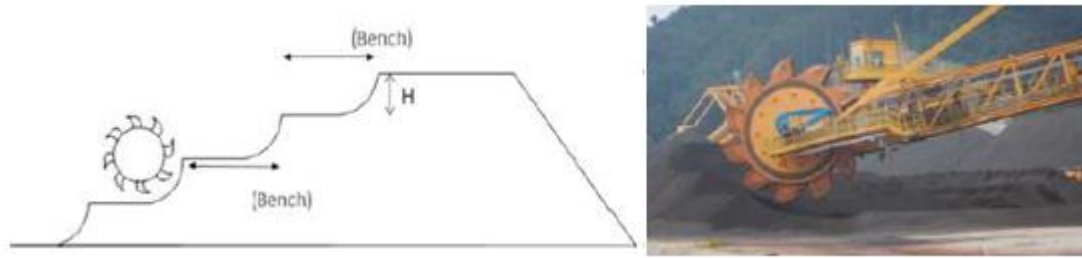


**Figure 30 - Change hatch average per year of vessel manufacture**

### 3.3.2 Equipment maneuver

The operational shutdown called "Equipment maneuver" consists of the bench reclaiming model, after 21m the equipment stops operating to return to the beginning of the bench, this value of 21m is standard and was defined by the product quality team to ensure homogeneity of material. Considering that the machines are of the same model, same performance capacity, both in

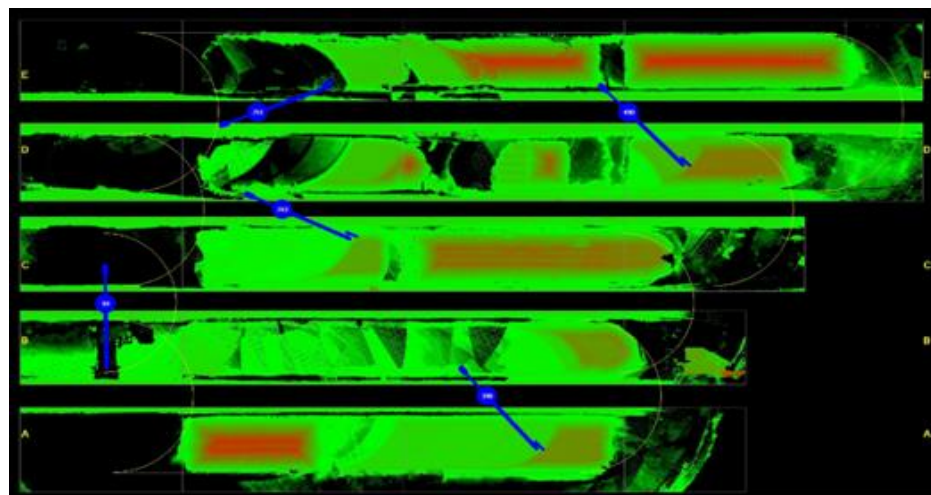
automatic operation and the distance is standard (21m), the shutdowns should have variations only due to the height of bench.



**Figure 31 – Reclaiming model by bench**



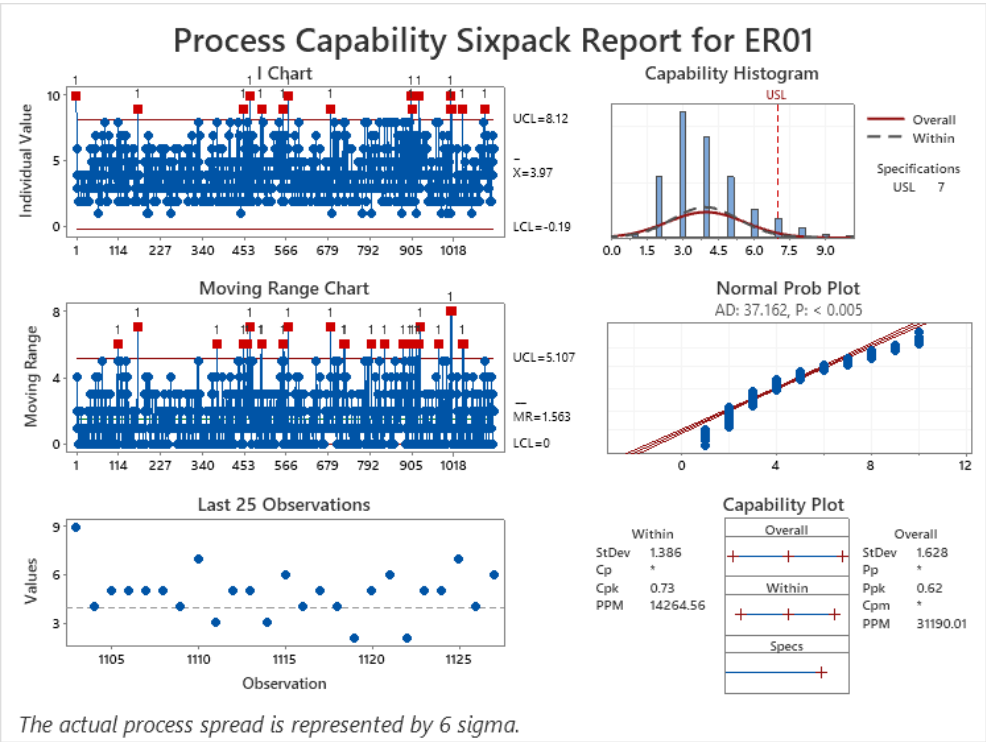
**Figure 32 – Reclaiming operation by bench**



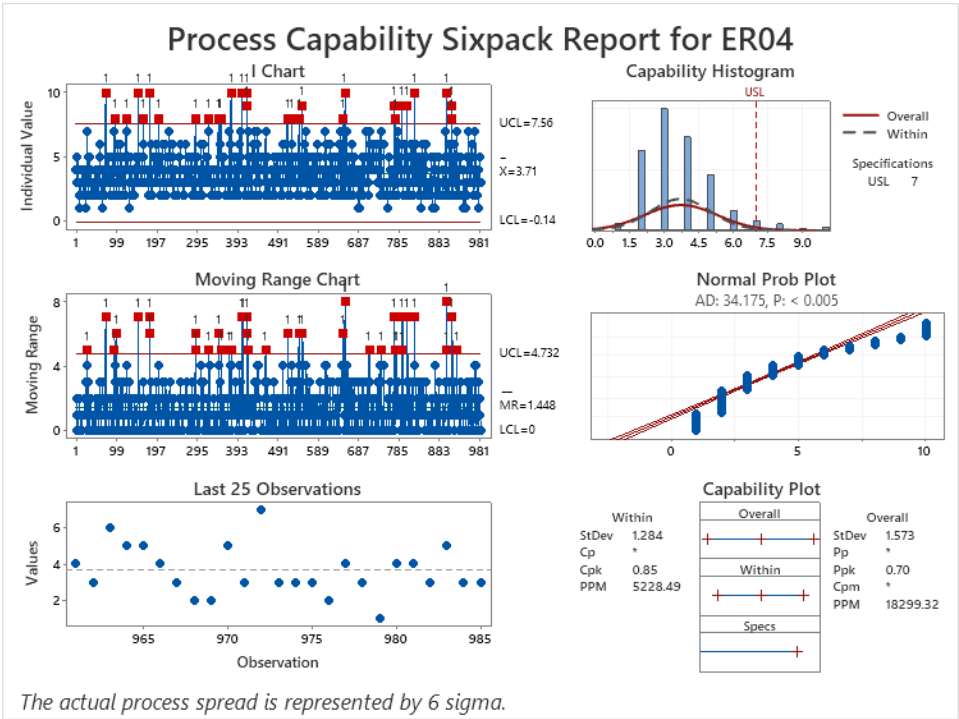
**Figure 33 – Yard at Malaysia distribution center**

The process was statistically analyzed and proved to be out of control in a non-normal distribution, the events were evaluated individually since the conditions of the event are repeated in an automated operation. This event is not accompanied by the operation because it is understood

that it is automatic and is at its optimal point, the fact that it takes a few minutes also contributes to the importance of deviations not being properly addressed.



**Figure 34 - ER01 equipment maneuver statistical analysis**



**Figure 35 - ER04 equipment maneuver statistical analysis**

### 3.3.3 Bad weather

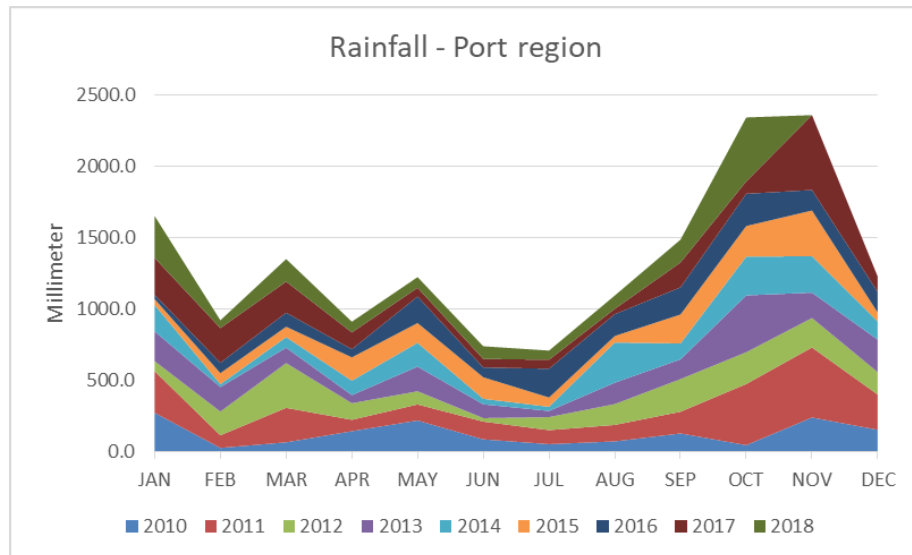
To maintain the quality of the product requested by the customer, in conditions of heavy rain the operation must be interrupted, and the hatches closes. The definition of what will be considered heavy rain is given by the ship's captain according to his perception. Bad weather events cannot be improved statistically, as they correspond to factors that are not controllable by the process, as we can see (Figure 34) in the rainfall history, the rainy season does not fulfill a well-defined seasonality eliminating possible gains even for planning purposes. Alternatives with new technologies that modify the process allowing operation in conditions of heavy rain should be studied.

JABATAN METEOROLOGI MALAYSIA													
Records of Monthly Rainfall Amount													
Station: SITI AWAN													
Latitude: 4° 13' N													
Longitude: 100° 42' E													
Elevation: 6.8 m m Unit: millimetre													
Year	Month												ANNUAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
2010	273.8	27.8	66.8	144.6	219.4	87.8	53.8	73.4	128.6	47.0	240.2	154.4	1517.6
2011	291.6	88.2	241.6	79.8	112.6	124.2	98.4	115.6	152.7	428.4	491.0	247.0	2471.1
2012	69.6	166.2	313.4	116.4	92.2	24.2	91.2	145.4	228.6	223.0	206.8	156.8	1833.8
2013	208.8	172.2	108.0	56.8	172.8	97.2	43.0	150.0	138.4	398.0	178.0	228.4	1951.6
2014	185.6	19.6	74.2	101.2	166.8	38.6	29.2	281.6	111.6	271.4	255.4	127.8	1663.0
2015	40.6	77.4	72.7	163.0	138.8	150.6	65.2	45.8	202.8	214.6	319.8	62.0	1553.3
2016	30.2	72.2	98.2	57.4	185.8	68.4	201.6	153.0	189.8	225.6	143.6	143.8	1569.6
2017	258.5	243.8	218.2	117.9	61.8	60.0	63.4	37.6	174.8	88.2	524.8	108.4	1957.4
2018	293.6	54.5	157.6	75.0	74.4	88.8	63.6	93.2	159.4	447.0			-

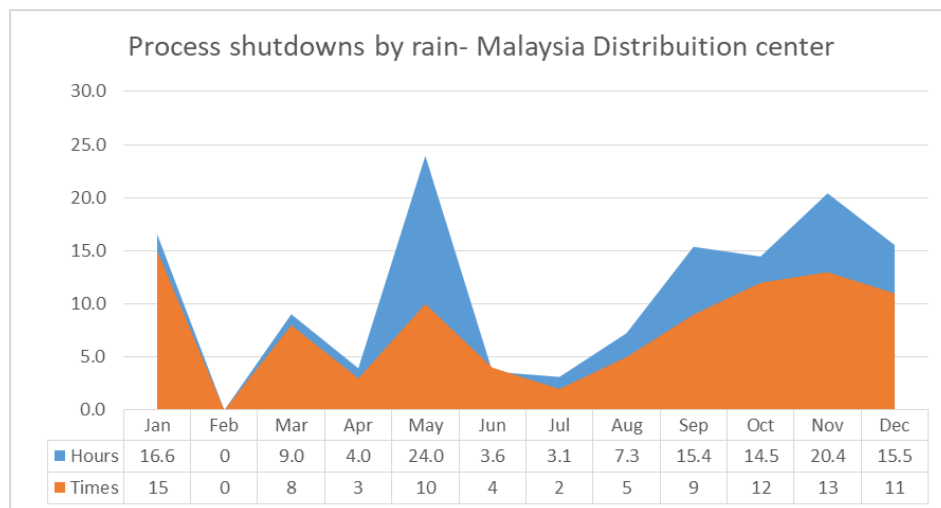
  

Records of Number of Raindays													
Station: SITI AWAN													
Latitude: 4° 13' N													
Longitude: 100° 42' E													
Elevation: 6.8 m m													
Year	Month												ANNUAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
2010	21	5	14	17	12	16	16	14	14	9	21	22	181.0
2011	17	6	22	10	13	9	11	9	11	19	25	19	171.0
2012	11	16	17	15	13	8	12	8	17	19	24	21	181.0
2013	14	15	9	12	14	7	10	14	16	22	23	21	177.0
2014	10	2	9	16	14	3	8	16	13	19	25	19	154.0
2015	7	5	9	16	12	8	13	14	15	13	23	14	149.0
2016	8	12	5	5	21	9	14	9	16	17	20	16	152.0
2017	17	14	16	18	13	9	7	22	13	14	23	10	176.0
2018	19	6	18	14	16	9	6	8	15	24			135.0

Figure 36 – Rain data in the Port region (Source: <http://www.met.gov.my/home>)



**Figure 37 - Rain graph in the Port region**



**Figure 38 - Process shutdowns by rain in 2019**

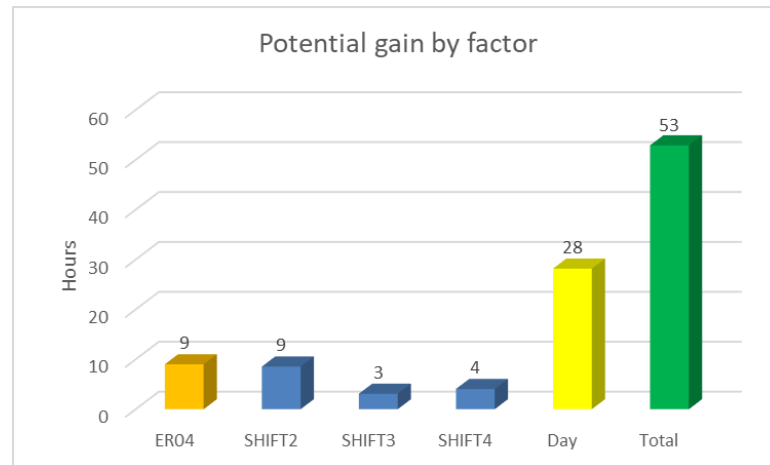
## **4 Results**

This study shows the main losses from the ship loading process at the distribution center in Malaysia and analyzed the 3 main ones that represent more than 50% of the total operational losses. Through the statistical analysis, quality tools and suggestions of new technologies, the analysis stratified what factors and how to act to improve the process with the measurement of potential gains that can be captured. It is important to emphasize the demystification of common knowledge based on perception and not on data, as for example the Equipment Maneuver considered adequate by the terminal proved to be a critical problem and the year of manufacture of the vessel considered a problem to be treated showed no influence on the result.

### **4.1 Change Hold/Hatch**

#### **4.1.1 Statistical performance**

Variations in relation to the original machines, operating shift and difference between day/night operations were analyzed. The analysis shows that just balancing the best average performance of these factors would be enough for a potential operating gain of 53 hours, which would be due to the terminal's current performance of around 200Kton with the average price of \$ 127.53 per ton of iron ore in 06 / 09/2020 (Source: <https://www.investing.com/commodities/iron-ore-62-cfr-futures>), and this would represent a potential gross revenue of \$ 25,506,000.00. Based on this information, daily work to monitor the events using the control chart and treatment of outliers to identify the best practices and which factors imbalance the performance should be initiated, this work will probably improve the benchmarking value as well.



**Figure 39 – Potential gain by statistical factor**

#### **4.1.2 Distance between origin and ship loader**

The large distance between the machines at the origin and the ship loader that causes operators to be afraid of the exact moment of return of the flow, where a failure could generate a material fall accident on the ship's deck, can be improved by reducing this distance using an intermediate silo as already used in the port of Hamburg in Germany (Figure 41). This reduction would bring reliability and would transform the current 12min to 15min to 2min to 3min, reducing all portion change time. This potential gain cannot be measured since it refers to human attitudes, but it would obviously bring greater safety to the operations and reduction of time waiting for material in the change hatch.



**Figure 40 - Intermediate silo at the port of Hamburg in Germany**

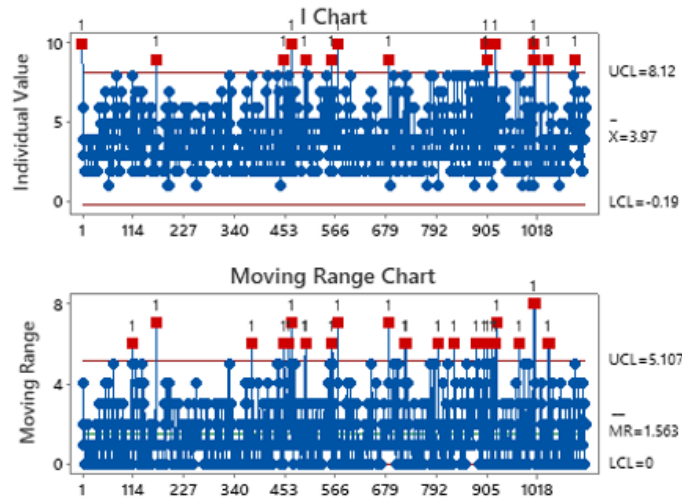
## **4.2 Equipment maneuver**

The equipment maneuvering process should present a statistical study in normal distribution with few opportunities for improvement, due to being repeated under the same operating conditions and with similar machines, but the numbers showed the opposite with great variation in uncontrolled processes. Despite being the second biggest operational loss in the process, the myth of automatic operation leads to the stoppage not properly monitored.

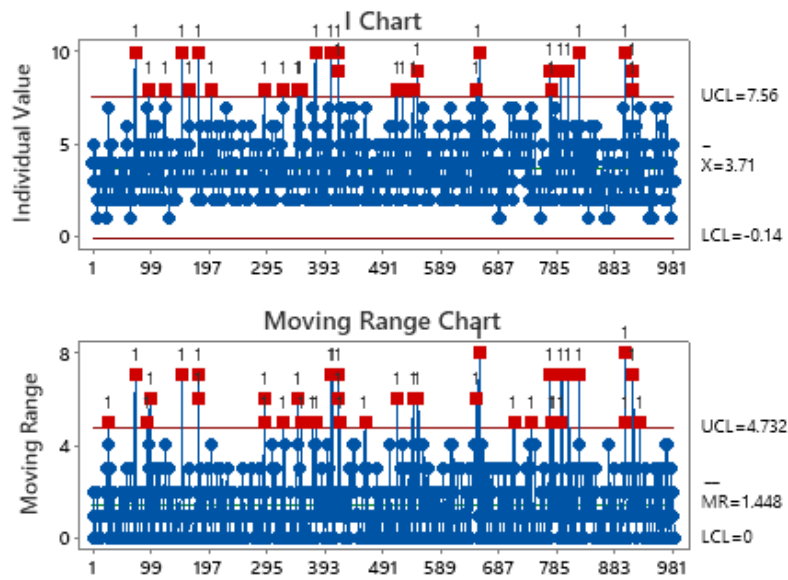
It is necessary to start a daily monitoring process via a control chart using the specification limit as the trigger to identify faults to be repaired with the automation team, once the work has been carried out by identifying possible faults in the automation system, the stacking model (Figure 44) can be studied to optimize the results. This study showed that this event that is considered stable and with no opportunity for improvement has to be monitored and has great opportunities for reducing losses.

During the implementation of management by control chart, the creation of a minimum specification limit is also necessary since it is not possible to perform a bench change in short time such as 1 or 2 minutes.

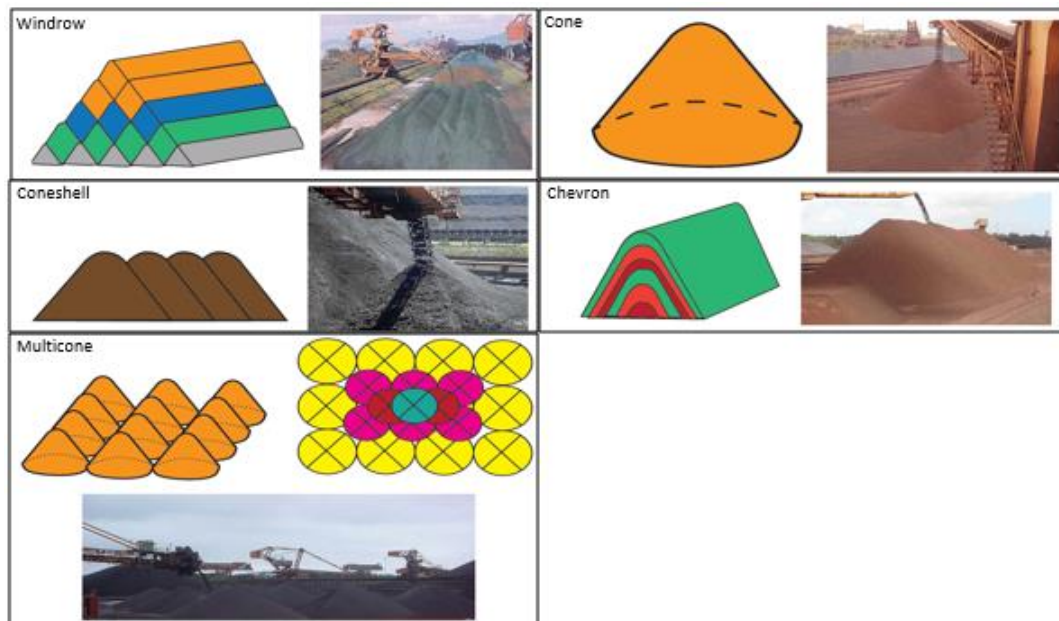




**Figure 41 - Equipment maneuver control chart ER01**



**Figure 42 – Equipment maneuver control chart ER04**



**Figure 43 – Stacking models**

### **4.3 Bad weather**

The loss due to bad weather in 2019 was approximately 120h, represented by the terminal's current performance around 500Kton, which using the average price of \$ 127.53 per ton of iron ore on 06/09/2020 (Source: <https://www.investing.com/commodities/iron-ore-62-CFR-Futures>) would represent a potential gain in gross revenue of \$63,765,000.00 if fully eliminated. For the total elimination of this loss, the implementation of a new technology would be necessary, we can mention two options to be studied, the first on a cover (Figure 42) for the terminal which would have a high cost and is not a common practice and the second is covering the hatch with a retractable canvas, known as Ecoload (Figure 43), this practice is already used in some ports in Europe.



**Figure 44 - Terminal cover construction**



**Figure 45 – ECOloading technology**

## **5 Discussion**

This study aims to show that it is possible to use statistical tools in the sectors of the company by making it a fundamental part in strategic planning to make the most assertive decisions. Statements of means and statistical methods that can be used to solve problems were implemented in addition to addressing the use of statistical tools as a basis for analysis to find the best solution since the degree of importance that managers give to statistics and their view as organizational problem solving is still evolving.

The approach of well-known methods made it possible to identify significant points of improvement at almost zero cost, thus avoiding the implementation of costly projects that would be implemented without due knowledge of the process; based on simple calculations and common sense.

With the results obtained, it is possible to visualize that with the use of even more advanced statistical tools and new developing models as guides will ensure productivity and assertiveness in decision making.

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