FINAL PROJECT REPORT

GROUP - 2

PRODUCTIVITY AND QUALITY ENGINEERING

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Contents

Overview

- The COVID-19 epidemic has exacerbated supply chain concerns. The economic situation has gotten increasingly difficult, and sustainability is becoming more important. According to an expert, customers might expect supply shortages and price rises. Products often reach customers via a network of organizations that includes producers, logistics firms (which offer storage, distribution, and transport), and retailers. Not surprise, the entire system is quite complicated.
- There is an entire concept of modern supply chain management (SCM) devoted to making supply networks far more interconnected than they were previously. When done correctly, it may dramatically increase company performance while also helping the economy and society. However, this long-term attempt to make the entire system more efficient has been hampered by a slew of issues in global supply chains.
- In 2021, three major concerns emerged. The first, and perhaps most evident to many of us, was the enormous strain on global supply networks caused by the COVID epidemic and the accompanying sequence of lockdowns and restrictions that varied in timing and intensity from nation to country.
- Second, the economic and corporate climate has become increasingly difficult.
- Finally, the environmental effect of logistics and supply chain operations is becoming more generally recognized.
- Global supply chains have lately been a bigger issue especially when a customer order something internationally. Customers want products that can meet their requirements and good quality. In addition, they want the product fast and on time. Customer loyalty is built on trust, so one missed delivery can compromise that trust and cost you a customer for good. The supply chain is the most important factor to convert the promise.
- Focus: Improve Customer Delivery
- Sections: Planning for prevention & Solutions for issues

Process Flow Chart

Supply chain management workflows, often known as flow charts, depict the particular processes necessary to complete end-to-end product delivery. Material management, processing and packaging, inventory management, order fulfillment, product delivery, and so on all take place in order for a product to reach the client or customer. Most firms' supply chain management processes may benefit from several enhancements, and workflows and flow charts can assist in identifying such improvements. Each action in the supply chain management process should be studied separately, as well as how it influences the entire supply chain process and customer experience.

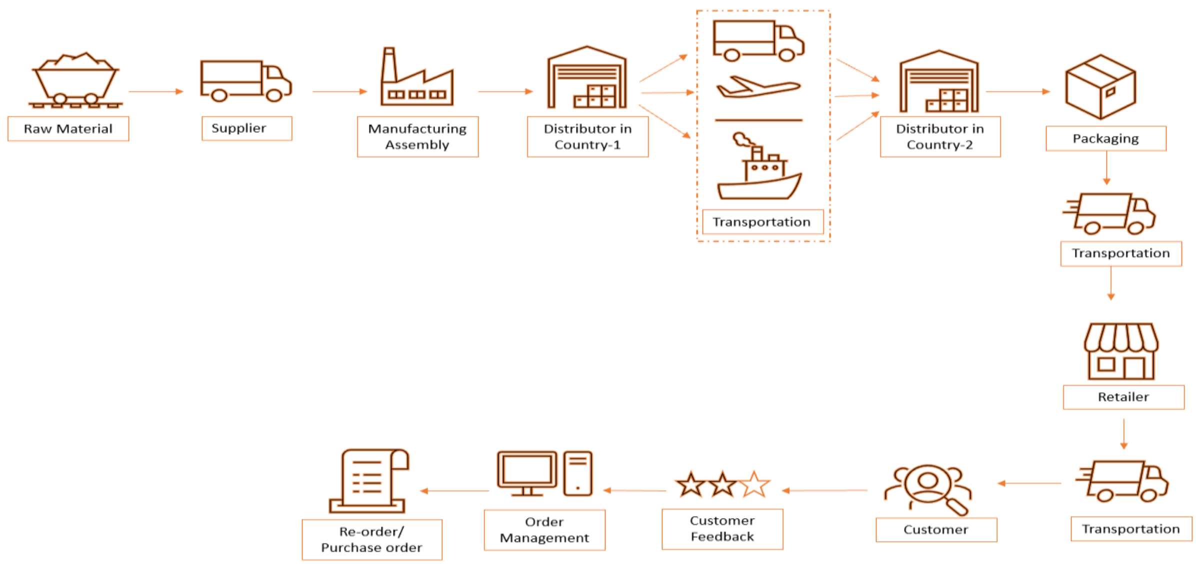


Figure 1 – Flow chart of supply chain

As previously stated, there are several stages of the supply chain management process from start to finish, each of which may benefit immensely from the usage of flow charts and workflows. The number of complications that might develop from the start of the supply chain process (procurement) to the finish (distribution or delivery) is virtually limitless. These are the procedures that apply to most supply chain management tasks where flow chart creation and development may lead to continuous improvement!

1. Procurement: Purchasing raw materials or finished items from vendors is critical for supply chain efficiency. Using flow charts or processes can assist reduce instances of duplicate vendor analysis/research while also streamlining purchase order creation.
2. Material management: It is the purchase, examination, and storage of raw materials utilized in the manufacturing process. Adherence to company-defined procedures can minimize the amount of inspection mistakes, resulting in lower scrap rates and higher first pass yield.
3. Manufacturing & Production: Although some businesses may not consider manufacturing to be a supply chain management activity, it is an important component that lies in the midst of the supply

chain process (for manufacturers). In the manufacturing plant, flow charts can help to reduce lead times and boost equipment efficiency and utilization.

4. Order Management: The order management function is in charge of gathering, validating, and submitting all information needed to fulfill client orders. Using flow charts to capture essential phases in the order management process can assist to decrease order mistakes and boost customer satisfaction.
5. Distribution: The distribution function is in charge of everything from inventory and warehouse administration to the ultimate delivery of products to the customer. Using flow charts in the distribution process can assist to enhance inventory location accuracy, minimize wastage, and eliminate order fulfillment mistakes.

Assessment and Analysis of COPQ

COPQ is the cost of poor quality and the cost associated with providing poor quality products or services to the customers. For COPQ, it has five different contents which are process, internal failure, external failure, appraisal, and prevention. The team divides the delivery time of products to customers from one country to another country into three different processes which are order management, supplier, and packing & distribution. For the details, these processes will be analyzed from four different fields.

For order management, it stands for how the suppliers or manufacturers prepare the order from the company. In internal failure, the manufacturers will face the following issues which are short of labor, equipment quality, and money issue. When the supplier or manufacturers have an order from the company, internal failures will lead to the issues of late products delivery. For external failures which are unpredictable factors, repeated quality issues, and production efficient drop, there are unpredictable endanger which the failure of manufacturing equipment and weather issues to delay the time of finishing the product. In addition, the appraisal of the order management will be keeping track of the feedback from the customer and placing purchase orders. For the prevention of the order management will require suppliers to hire more employees and regular check for the equipment. It will maintain the quality of the product and make sure the product will be delivered to the customer on time. For the supplier and packing & distribution, the team provides the corresponding internal failure, external failure, appraisal, and prevention as shown from the COPQ table.

Process	Internal Failure	External Failure	Appraisal	Prevention
Order Management	Short of labor Equipment quality Money Issue	Unpredictable endanger Repeated quality issues Production efficiencies drop	*Maintenance feedback from customer and placing purchase order	Hiring more employee Regular maintenance on equipment Keep analysis on feedback from customers
Supplier	Shortage of raw material Bad quality on raw material	Cannot delivery raw material to manufacturer company on time	* keep quality of raw material products *Quality auditing of the raw materials	Has backup material supplier Keep tracking on material & stored specific amount of raw materials
Packing & Distribution	Shortage of transport company Requirement of packaging	Weather issues Lockdown caused by covid-19	*Pre-check packaging requirement from different countries *Use standard packaging size of each product	Backup transport company Notification to the customers

Figure 2 – COPQ chart of supply chain

Affinity Diagram

The Affinity Diagram aids diagnosis by grouping facts, opinions, & issues. This allows us to capture the key take aways from the COPQ into groups to understand if there are adjacent issues or one group that has a greater amount of issues. Two items that are heavily overlapping are Cranes & Trucks in the Logistics column. Knowing that these are both issues and that they go hand in hand we can understand their full interaction and what can be done to address these issues.

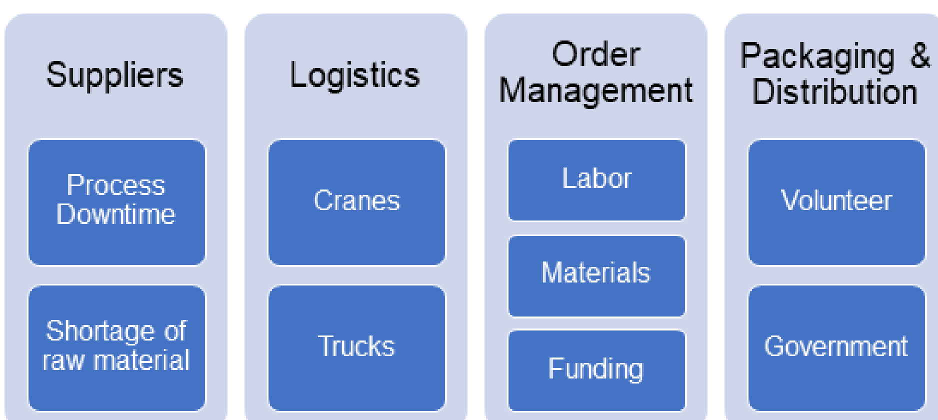


Figure 3 – Affinity diagram for the supply chain

Six Sigma DMAIC/DFSS

Define Phase

Deliverables:

- Define the problem.
- Determine the desired state.
- Complete pre-project administrative work.
  - -Secure resources.
  - -Create the team.
  - -Establish a business case.
- Create the project charter.
- Draft of high-level flow chart of the process

Figure 4 – Define phase chart

Problem Definition:

- There is delay in customer delivery and that results in frustrated customer returning the products
- Customers want products that can meet their requirements and good quality. In addition, they want the product fast and on time. Customer loyalty is built on trust, so one **missed delivery** can compromise that trust and cost you a customer for good. **The supply chain is the most important factor to convert the promise.**
- The project scope was limited to the supply chain
- **Focus**: Improve Customer Delivery
- We form the team to execute this Six Sigma project

Voice Of the Customer (VOC)

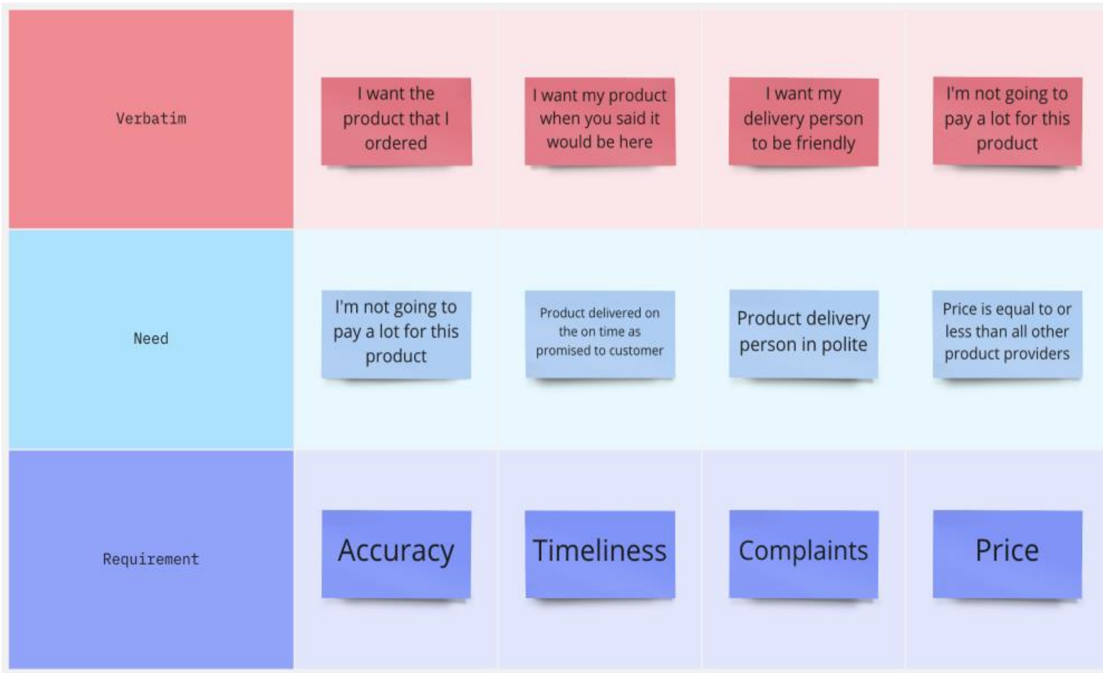


Figure 5 –Define phase for verbatim, needs, and requirement

By creating the Voice of the Customer, we found out the following requirements of the customer:

1. Accuracy of the product that customer ordered
2. Product should be delivered on time
3. The delivery person should be polite
4. No unnecessary costs

Analyze Phase

After the data is measured we then need to analyze the collected data to get a better understanding of its characteristics and hypothesis what can be done to improve the results.

Objectives to be achieved from analysis:

Interpret and understand the data collected from a statistical standpoint.

Using tools analyze the data and trends.

Hypothesize actions that can be taken in the improvement phase to correct unfavorable trends.

Step 1: Interpret Collected Data

To better understand the data collected in Step 4 of the Measure Phase we use statistical methods and programs like Minitab. This allows us to lay the data out in a way that can be better understood and analyzed.

Step 2: Analyze Collected Data

With our data in Minitab we could then use this tool to analyze the large amount of data collected and further refine the values. We used Descriptive Statics to further define the Delivery Lead Time and found that in addition to the high standard deviation we have a large variation between the minimum and maximum lead times.

To understand how the data is distributed we used a Normal Probability Plot and were able to determine that with the graph shown and a P-value of 0.160 that our data follows a normal distribution

Descriptive Statistics: Delivery Lead Time

Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Delivery Lead Time	100	0	108.67	0.830	8.30	86.98	103.13	108.43	114.52	127.05

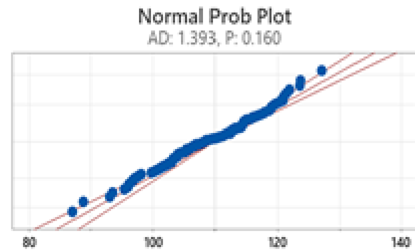


Figure 6 – Descriptive statistic and normal probability plot

Looking at the Process Capability Sixpack we were able to get a much greater understanding of the data that was collect. With a LSL = 101, USL = 119, & Mean = 108 it is evident the process is leans more toward the LSL. We had a low Cp = 0.33.

When looking closer at the Capability Histogram we find a couple trends that will need better understanding. Although the data is normally distributed we can see that the population is bimodal and there is a fear that there are two populations. The stability of the data may come into question but at this time cannot be determined.

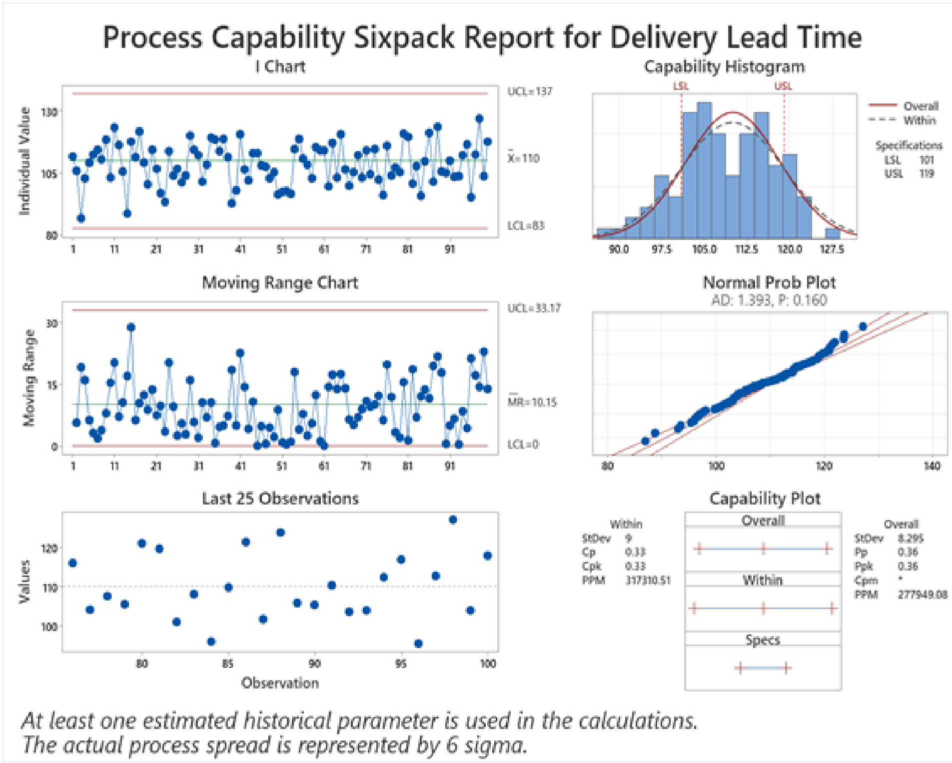


Figure 7 – Process capability sixpack report for product delivery lead time

Step 3: Test theories and hypotheses

With the process leaning more towards the LSL we should make attempts to increase the mean to attempt to center the process. To improve the Cpk and to fit the project in the specification limit we should try to reduce the standard deviation.

A better understanding of the bimodal population should be completed to determine if we have two populations and how to mitigate that.

Measure Phase

After defining the problem and identifying the objectives we decided to move on to the next step to measure the process.

Objectives to be achieved from studies:

We measure the process performance in its current state to understand the problem.

Understanding the degree of different causes adding to the problem with the help of data.

Validate results to overcome resistance to accepting and implementing a change with results.

Step 1: Document the Process:

To begin with measurements, it's vital to understand the flow of the process.

This step records the activities under study and the sequence of events undertaken in the entire supply chain.

A useful tool to undertake the desired task is a process flow diagram.

Step 2: Identifying key areas that can cause an error

• Using a fishbone diagram, we have been able to identify the major cause for adding up the lead time in the manufacturing process.

• We included all segments of the supply chain to have a holistic view of the targeted problem.

• Furthermore, we did a different test to identify the root cause and the possibility of success.

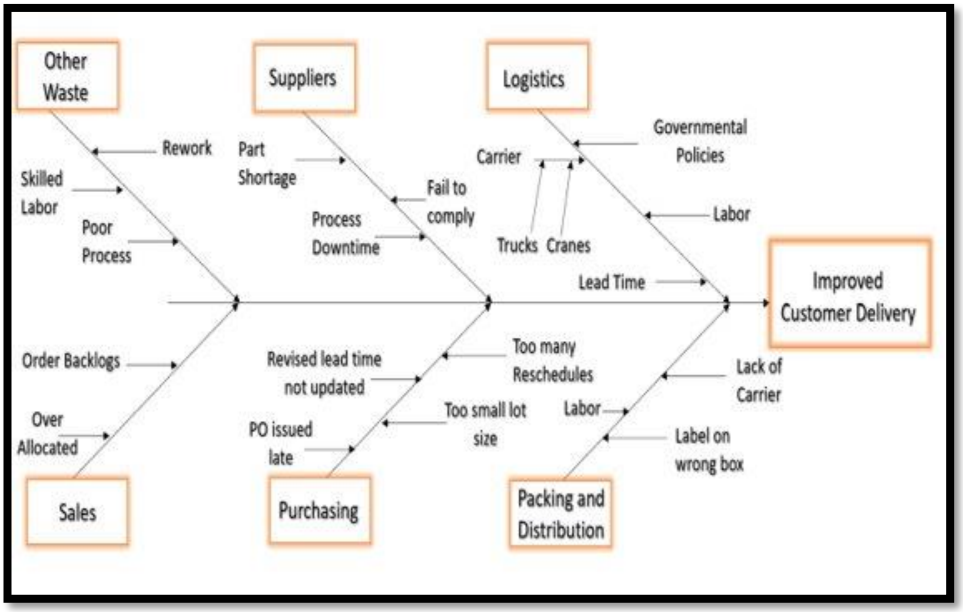


Figure 8 – Fishbone chart of supply chain

Step 3: Understanding the most critical problem

We are facing huge problems in the post-pandemic world to fulfill the high customer demands resulting in loss of opportunity and even loss of loyal customer base.

By using the Pareto chart, we mapped the process lead-time involved in manufacturing.

After further investigation by professionals, we have found the supplier lead time is a major source of delay.

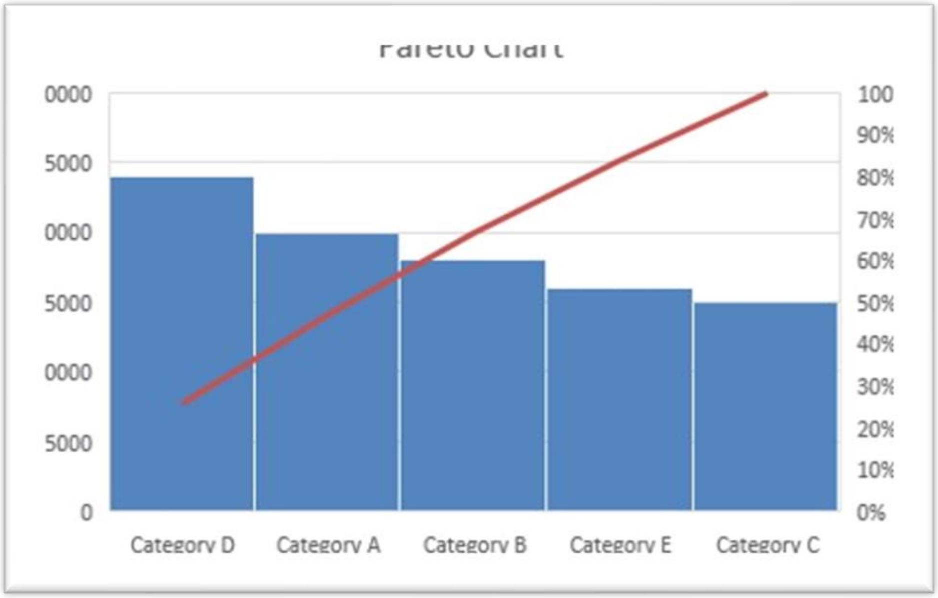


Figure 9 –Pareto chart

Step 4: Measure the current process

We identified the total length of duration associated with all the processes; it was observed that the lead time was 110 days with a standard deviation of 9 days. This was very large and had intangible problems like inventory and even in some cases missing the stated promise date.

Step 5: Draw a conclusion

So, we undertook a market study to shift the supply chain to a closer geometric region like Mexico which can significantly reduce the lead time-saving cost of warehousing as well as can help to take advantage of Just In Time inventory

Improve Phase

The improvement phase is where the team solves problems. They develop solutions, pilot process changes, implement their ideas and collect data to confirm they are making measurable changes. In the global supply chain issues, the improvement phase will be focusing on building local & overall capacities, becoming strategically lean, building strong connections, and digital transportation in warehouses.

For building the overall & local capacity, the team brings up two different ways to shorten the time for delivering the product to the customers. In terms of the overall capacity, the manufacturing factories can be set in different countries and increase the number of products from different countries' factories. In addition, the idea of local capacity will lead to setting up manufacturing factories in the customer's country and will shorten the delivery time to the customer, however, it might increase the spending on the labor and rental for the companies. For the digital transportation, the team suggests the warehouse management can be transferred into digital transportation system. By using digital transportation systems, the warehouse management will be able to easily track and manage the warehouse's storages and leads to better and more efficiency handling the shipping & restocking of the products. In addition, digital order management can make the manufacturer prepare and track the order from the customer easily. However, building a strong connection with the customer and having strategically lean for the customer are other improvements for this phase. Building a strong connection and having strategically can know the demands from the customer's company from nowadays and future. Therefore, the manufacturer or distributor company will have a plan to prevent unpredictable or predictable issues happening.

Control Phase

For the control phase we decided to deliver the following:

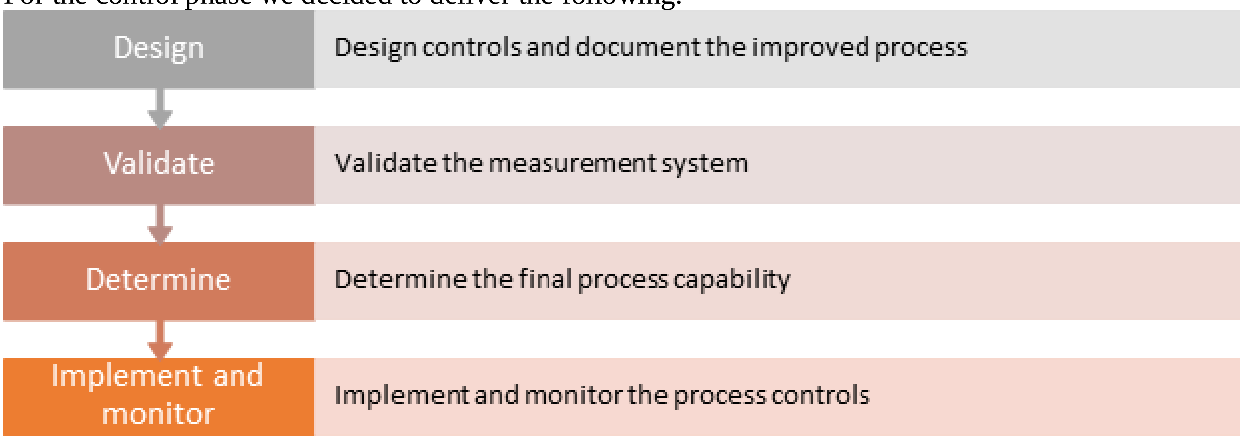


Figure 10 – Control phase chart

- By creating a **Process Control Plan,** we were able to define what needs to be done to ensure the processes operate effectively and standardize reactions
- By creating **SOPs,** we can create standard work allowing us to create repeatable results
- Implementing **Change Management** allows us to create a system to monitor changes and ensure changes have merit

Quality Function Deployment (QFD Matrix)

Introduction

QFD is a focused process for carefully listening to the voice of the customer and then delivering their needs and expectations successfully. Quality is a measure of customer satisfaction with a product or service in QFD. QFD is a systematic strategy that employs seven management and planning tools to rapidly and efficiently identify and prioritize customer expectations.

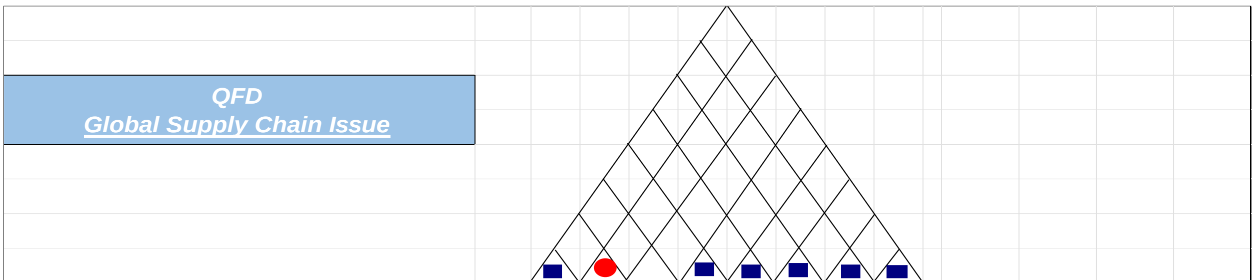
The QFD technique focuses on the most significant traits or qualities of a product or service. These are made up of client wows, desires, and musts.

Once the traits and qualities have been prioritized, QFD assigns them to the appropriate organizational function for action. Thus, QFD is the application of customer-driven attributes to an organization's responsible functions.

Analysis

There are too many elements will influence customer delivery. We've outlined some of the important customer needs and functional requirements or Quality Characteristics, and we'd like to know how they affect the supply chain process, which ones have a big influence, which ones don't, and how they interact with one another.

House Of Quality



Customer Requirements \ Quality Characteristics	Priority	Delivery on time	Undamaged deliveries	No extra costs	IT Services	Reliable Manufacturing line	Order flexibility	Meet demand quantity	Improving transport
		■	●		■	■	■	■	■
Delivery	8	9	9	8					9
Cost	7	3		9				3	3
Product quality	6		8	3		9			
Real time Shipment tracking	5				9		8	8	9
Order Fulfilment	4	9	3		8	9	3	9	8
Quality Service	3	3	3		3	9	3	1	8
Environmental friendly	2			1			9		
After Sales Service	1	1		3		1	9		1
CTQ Priority Score		139	141	150	86	118	88	100	195

LEGEND		
Priority	8	Highest
	1	Lowest
Relationships	9	Stronger
	3	Medium
	1	Small
	■	Positive
	●	Negative

Figure 11 –QFD of supply chain

Interpretation from the House of Quality

Through House Of Quality, we conclude that:

The customer needs which have relatively high impact are:

- Delivery
- Cost
- Product quality
- Real time shipment tracking

The most important customer need is faster Delivery

The functional requirements or Quality Characteristic which has relatively high impact are:

- Improving transport
- No extra costs
- Undamaged delivery

The most important functional requirement is Reliable Manufacturing line。

DOE/Experimental Design

The design of experiments (DOE) approach is a systematic method for determining the link between factors affecting a process and the process's output. To put it another way, it is utilized to discover cause-and-effect linkages. This data is required to control process inputs in order to optimize output.

This section focuses on the most critical client demand, improved delivery. We must determine which component is the most essential. We can provide consistent quality among the ideal values for the variables under examination. The procedure involves the potential factors, whose values are presented below.

Step 1: Acquire the inputs and outputs being investigated.

- **Output:** Improved Customer Delivery
- **Input:** A. Number of containers

  B. Number of cranes

  C. Number of ships

Step 2: Determine the appropriate measurement for the output.

Collect historical data through a sample survey as a response.

- Annual Customer Delivery time generally varies from 75 to 95 days (cycle starting from supplier to customer)

Step 3: Create a design matrix for the factors being investigated.

Step 4: For each input, determine the extreme but realistic high & low levels to investigate.

- Factor A: Number of containers
  - Low (-): 80

- High (+): 120

- Factor B: Number of cranes
  - Low (-): 8
  - High (+): 10
- Factor C: Number of ships
  - Low (-): 3
  - High (+): 7
- The design was a 2^3 factorial with 3 different factors

		Factorial Experiments 2^3 (Three Replications/Treatment)							Run Results			
Run	A	B	C	AB	AC	BC	ABC	Y1	Y2	Y3	Avg.	Var.
1	-1	-1	-1	1	1	1	-1	-1.33	0.26	1.26	0.063	1.698
2	1	-1	-1	-1	-1	1	1	2.69	2.73	6.25	3.888	4.176
3	-1	1	-1	-1	1	-1	1	4.18	-3.59	0.92	0.504	15.218
4	1	1	-1	1	-1	-1	-1	23.16	20.45	23.61	22.408	2.924
5	-1	-1	1	1	-1	-1	1	11.83	6.98	8.89	9.233	5.965
6	1	-1	1	-1	1	-1	-1	21.65	23.27	21.17	22.032	1.215
7	-1	1	1	-1	-1	1	-1	18.92	12.47	23.52	18.306	30.796
8	1	1	1	1	1	1	1	32.94	37.84	34.19	34.992	6.492
TotSum								114.05	100.42	119.81	111.43	68.48
SumY+	83.32	76.21	84.56	66.70	57.59	57.25	48.62					
SumY-	28.11	35.22	26.86	44.73	53.84	54.18	62.81					
AvgY+	20.83	19.05	21.14	16.67	14.40	14.31	12.15					
AvgY-	7.03	8.80	6.72	11.18	13.46	13.54	15.70					
Effect	**13.80**	**10.25**	**14.42**	**5.49**	**0.94**	**0.77**	**-3.55**					
Var+	3.702	13.858	11.117	4.270	6.156	10.791	7.963					
Var-	13.419	3.264	6.004	12.851	10.965	6.331	9.158					
F	3.625	0.236	0.540	3.010	1.781	0.587	1.150					
Var. of Model		8.56		StdDv	2.93							
Var. of Effect		1.43		StdDv	1.19							
Student T (0.025;DF) =				2.473								
C.I. Half Width =				**2.954**								
		Significant Factors & 95% CI Limits:										
Factor	A	B	C	AB	AC	BC	ABC					
Signific.	Yes	Yes	Yes	Yes	No	No	Yes					
LwrLimit	10.85	7.29	11.47	2.54	-2.02	-2.19	-6.50					
UprLimit	16.76	13.20	17.38	8.45	3.89	3.72	-0.59					

Figure 12 – 2^3 chart for the DOE assessment

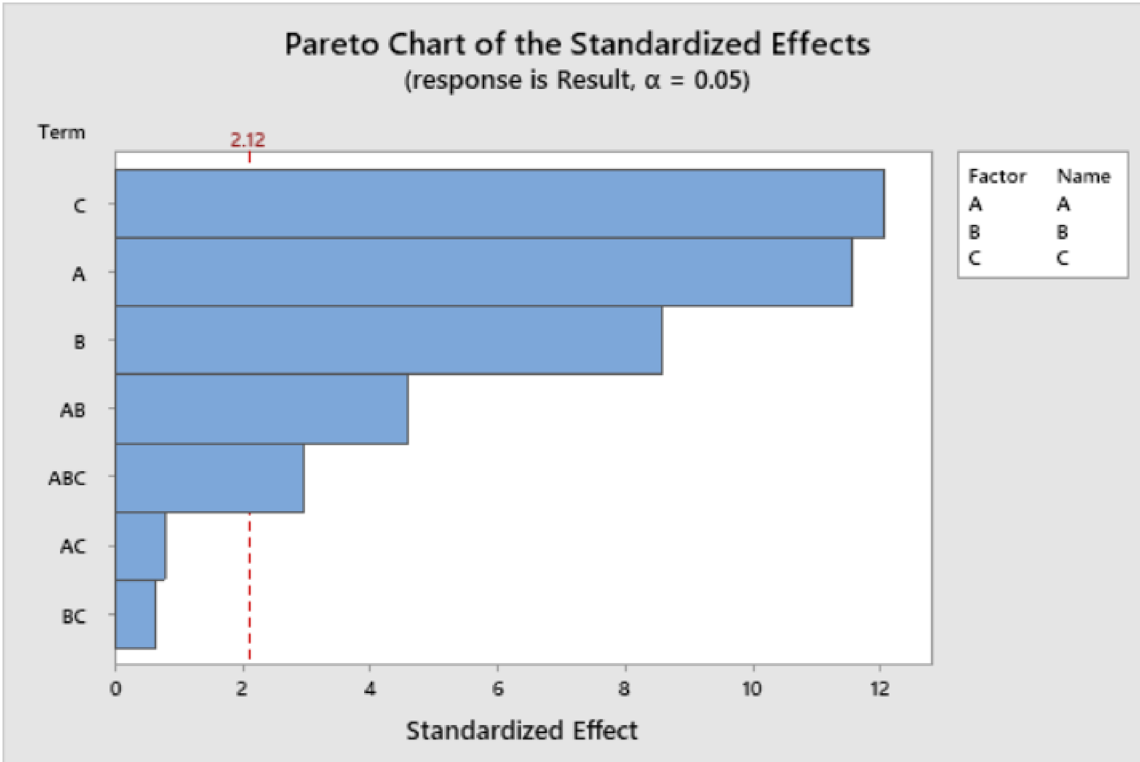


Figure 13 – Pareto Chart for the DOE factors values

We can interpret the following from above:

- We can see that since the value of AC & BC is less than 2.12 the interactions aren't significant.
- Also, note the values of other parameters are more than the set limit thus we can state that they are significant.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	3287.17	469.60	54.86	0.000
Linear	3	3021.85	1007.28	117.67	0.000
A	1	1143.24	1143.24	133.55	0.000
B	1	630.17	630.17	73.61	0.000
C	1	1248.45	1248.45	145.84	0.000
2-Way Interactions	3	189.78	63.26	7.39	0.003
A*B	1	180.96	180.96	21.14	0.000
A*C	1	5.29	5.29	0.62	0.443
B*C	1	3.54	3.54	0.41	0.529
3-Way Interactions	1	75.54	75.54	8.82	0.009
A*B*C	1	75.54	75.54	8.82	0.009
Error	16	136.97	8.56		
Total	23	3424.14			

Figure 14 – Analysis of variance chart

- Thus, we can say the A*C & B*C are not significant as the P-value is less than 0.05

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		13.928	0.597	23.32	0.000	
A	13.804	6.902	0.597	11.56	0.000	1.00
B	10.248	5.124	0.597	8.58	0.000	1.00
C	14.425	7.212	0.597	12.08	0.000	1.00
A*B	5.492	2.746	0.597	4.60	0.000	1.00
A*C	0.939	0.469	0.597	0.79	0.443	1.00
B*C	0.768	0.384	0.597	0.64	0.529	1.00
A*B*C	-3.548	-1.774	0.597	-2.97	0.009	1.00

- Thus, we can say the A*C & B*C are not significant as the P-value is less than 0.05

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.92584	96.00%	94.25%	91.00%

Figure 15 – Coded coefficients and model summary for DOE

- ***Factorial Regression: Response versus A, B, & C***

Regression Equation in Uncoded Units

Result = 13.928 + 6.902 A + 5.124 B + 7.212 C + 2.746 A*B + 0.469 A*C + 0.384 B*C - 1.774 A*B*C

Note: For model regression, we consider only the one that is significant and ignore the once that are not. Thus, in this case, we will not consider A*C & B*C

Plots:

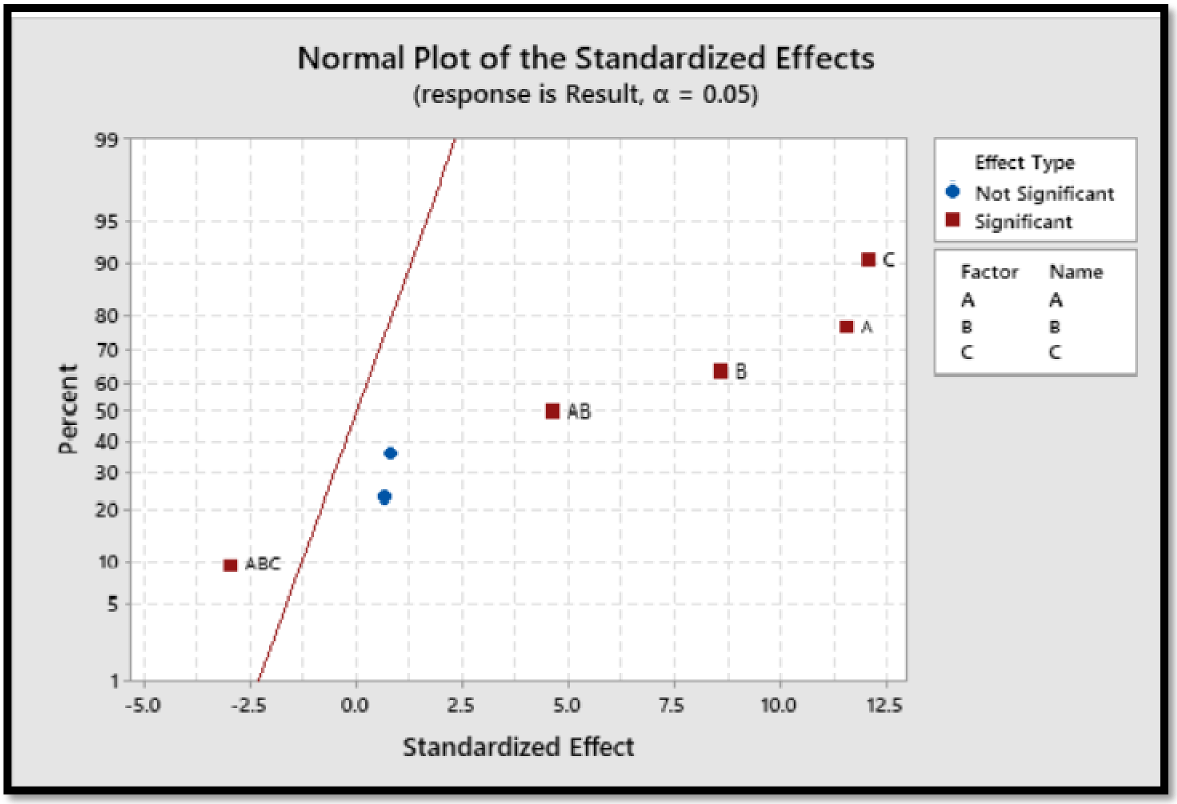


Figure 16 – Normal plot of standardized effects for DOE

We can interpret the following from above:

- The graph states that expect the value of BC & AC is not significant.
- Also, note Factor C is farthest from the normal plot and thus we can say it's the most significant.
- Additionally, we can state that the effect of interaction ABC is the least as it is closest to the normal plotline.

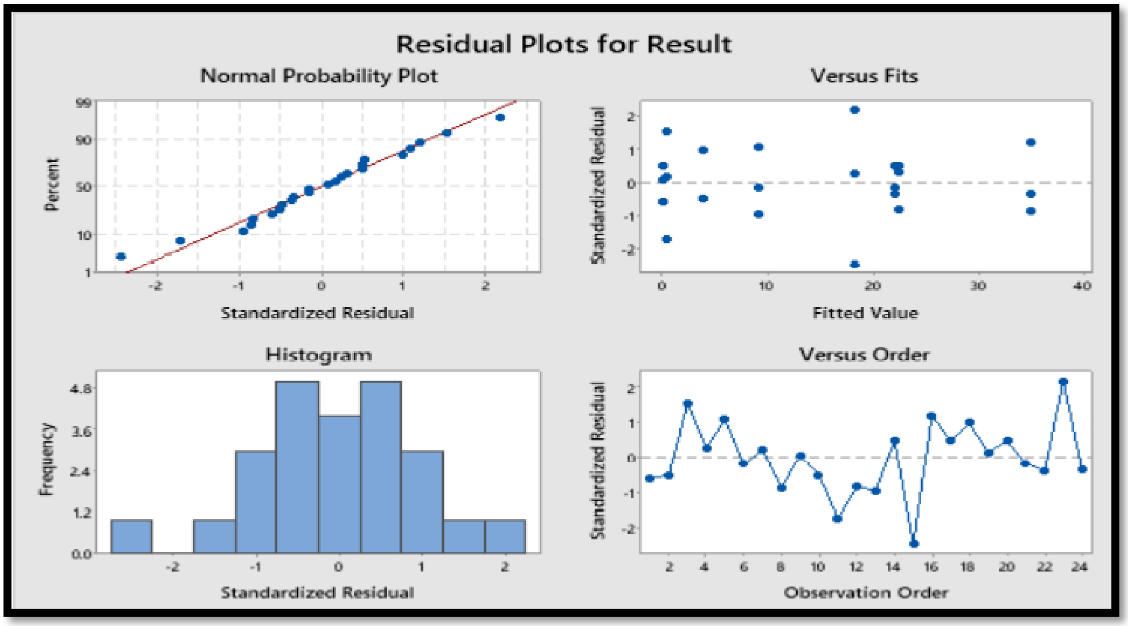


Figure 17 – Residual plot for the result

Fitted Plots for Response:

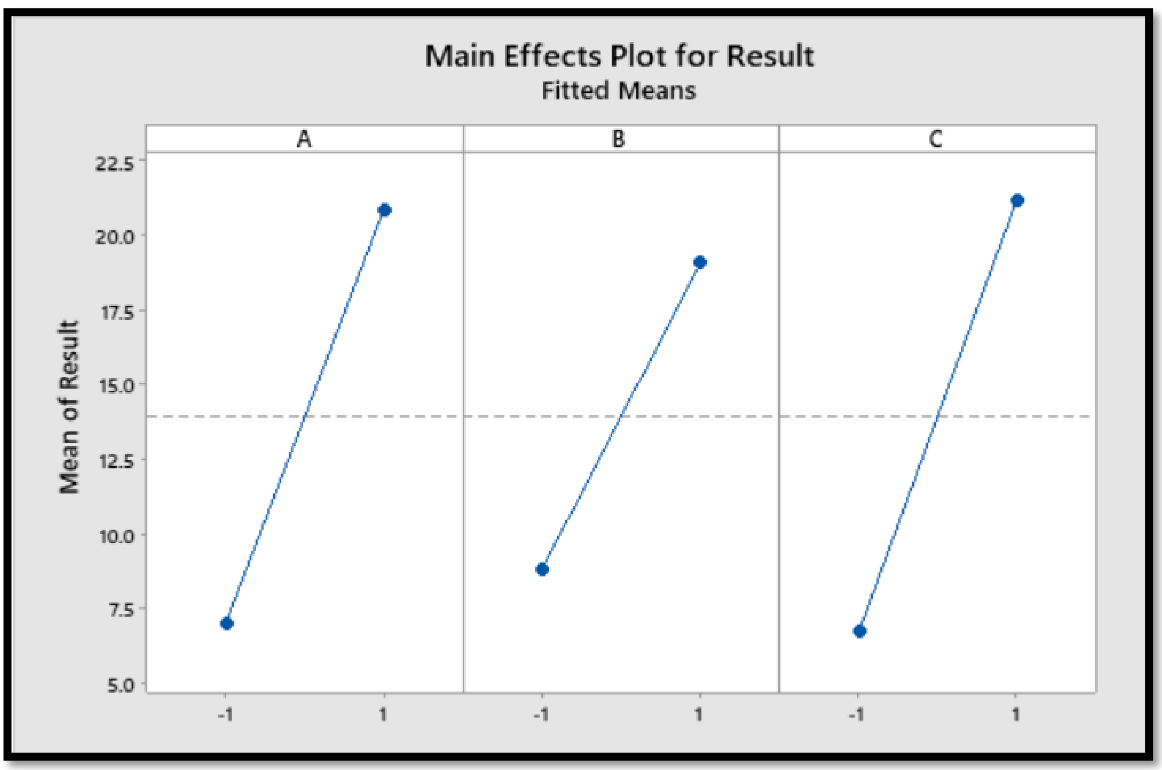


Figure 18 – Mian effects plot for result on DOE

- Here, we plot the effect of the factors

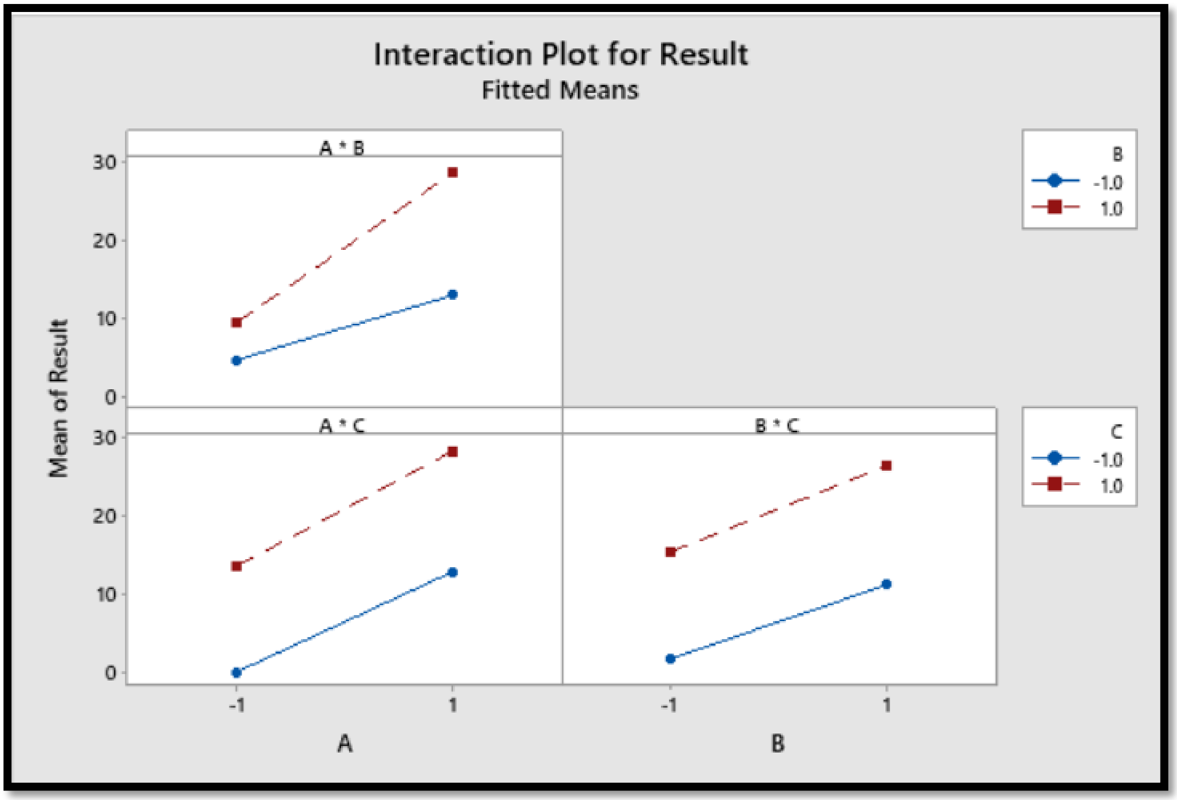


Figure 19 – Interaction plot for result on DOE

- We can say that since A*C and B*C are parallel they are not significant

Supply Chain and Lean/VSM

We used a value-value stream map to lay out all the steps in a process to help us determine value-added steps and non-value-added steps in the supply chain. By comparing the current state VSM & future state VSM we can visually show the improvements to be made to the process. To map all of the tasks in the process flow chart would be inefficient and should be broken up into key points to allow greater fidelity. We looked at the scenario of a ship arriving at a port, removing containers using a crane, setting the container on a truck, having the truck haul the container away, picking up a new trailer, then returning to crane.

Current State: 1 ship, 600 containers, 1 crane, 1 truck = 219.5 hrs/ship

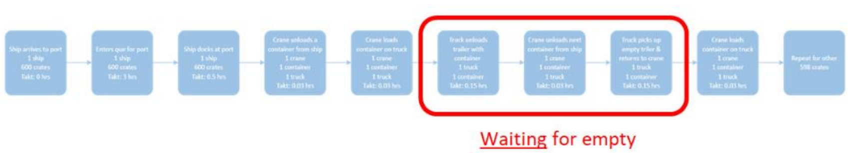


Figure 20 – Supply chain and lean manufacturing chart

Future State: 1 ship, 600 containers, 3 crane, 15 truck = 27.5 hrs/ship

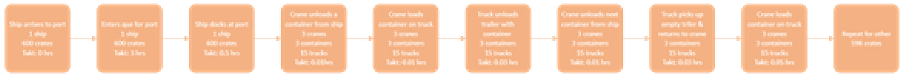


Figure 21 – VSM chart.

In the current state unloading 1 ship with 600 containers takes a total of 219.5 hours from start to finish. Looking at the Value Stream Map we can see that great deal of time was wasted waiting for a truck to unload the trailer with a container, pick up an empty trailer, and return to under the crane. To address this wait time we added 4 trucks per crane to sync with the unloading time of the crane. When a total of 5 trucks support 1 crane the takt times match and eliminate the waste of waiting times. To further reduce the time the ship spends at port 2 cranes will be added to allow for a total of 3 cranes to unload the ship in parallel, which each crane unloading a total of 200 of the 600 total containers. By addressing these two functions the time required to unload 600 containers from a ship was reduce from 219.5 hours to 27.5 hours, which is a 77.5% reduction in time.

Gage R&R Metrology MSA study

Gage Repeatability and Reproducibility (Gage R & R) is a method used to define the amount of variation in measurement data caused by a measurement system. It will compare the measured change to the total observed change to define the capability of the measurement system. Measurement variation includes two important factors which are repeatability and reproducibility.

Repeatability is the variation between successive measurements of the same product, same factor, and same time interval by the same person using the same gage. Reproducibility is the difference in the average of the measurements made by different people using the same instrument when measuring the identical characteristic on the same part.

All measurements are subject to some degree of variance or error. A robust SPC process requires accurate and precise data to have the greatest impact on product quality. As quality experts, the team needs to determine the percentage of variance caused by the measurement system. Gage repeatability and reproducibility is a proven method for assessing the capability of a measurement system. The Gage R&R study examined device reproducibility and appraiser reproducibility. By identifying where discrepancies exist in the measurement system, the team can take appropriate action and improve data quality

In the global supply chain system, the team use three different operators to track the time delivery of the containers from the suppliers to the customer. The sample will be the total time measurement with different operators and factors.

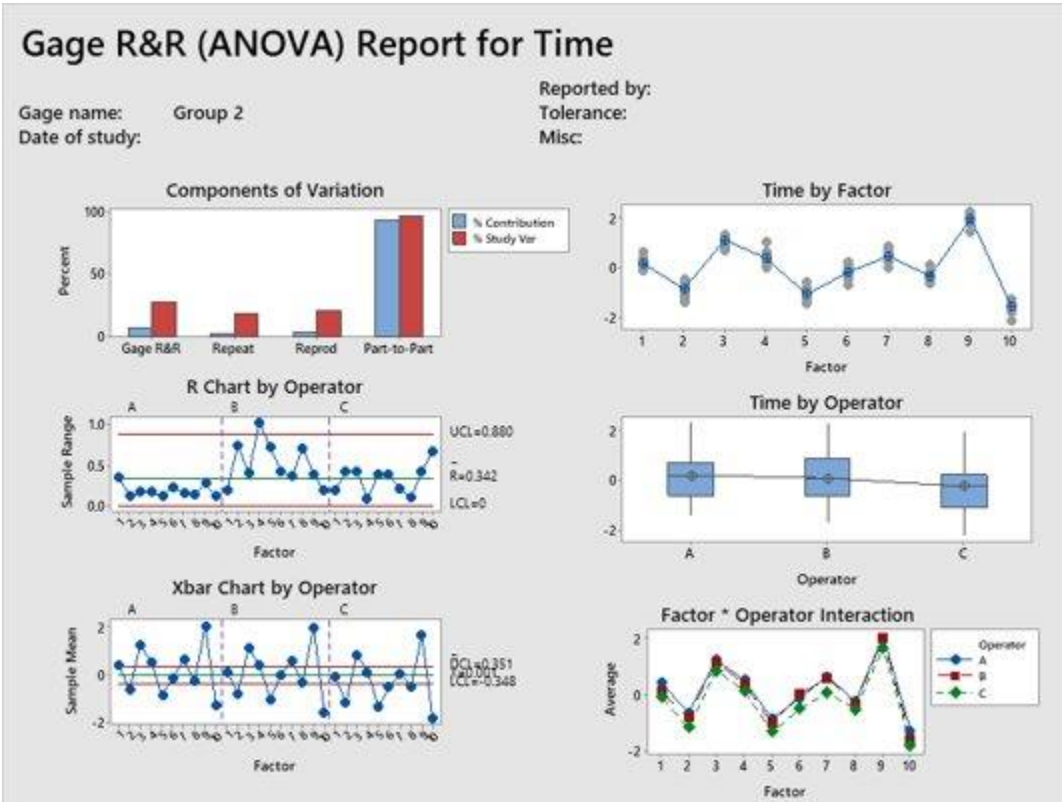


Figure 22 – Gage R&R report for time.

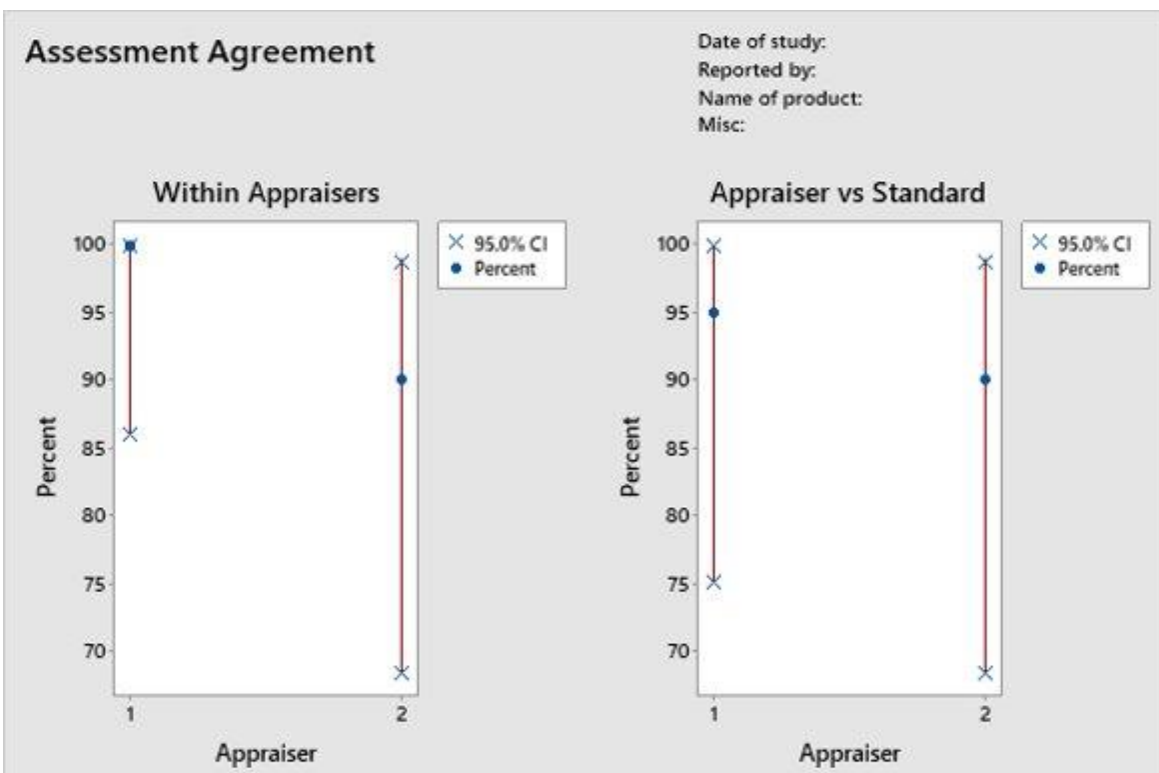


Figure 23 – GR&R assessment agreement

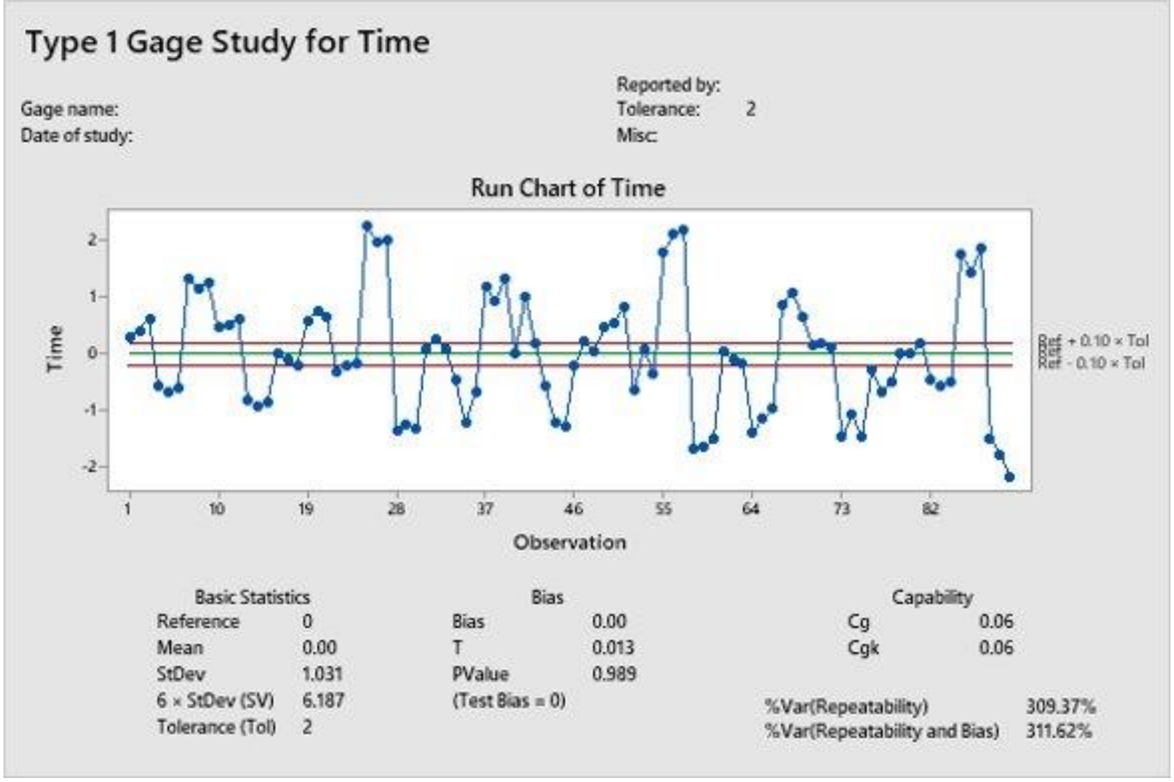


Figure 24- Gage study for time with % var repeatability.

From the result, the team analysis the operator C has the lower tracking product delivery time than other two operator. In addition, the percentage of variance repeatability is around 309% which is higher than the expectation. When comparing the appraisal and standard from assessment agreement, the appraisal has higher percentage rate than standard.

Acceptance Sampling Plan

- ***Why Acceptance Sampling for the global supply chain?***
  - Now, that the containers have arrived at the port it's very critical to make a sampling plan to accept or reject a batch of goods before they are sent to the inventory.
  - For this, our team decided to make a sampling plan.
  - Sampling is the process of evaluating a portion of the lot for the purpose of accepting or rejecting the entire lot
- ***Why is Acceptance Sampling used?***

  a) Cost of inspection is high in relation to the damage cost resulting from passing a defective product

  b) 100% inspection is monotonous and causes inspection errors

  - ***Sampling Risks*** - Greater administrative costs and less information about the product than provided by 100% inspection
- ***Steps were undertaken for the sampling plan:***

Figure 25 – AQL step chart.

- ***Evaluating the sampling parameters:***
  - **Lot size, N (total number of containers arriving)** = 1,000
  - **α probability (producer's risk)** = 0.05
  - **β probability (consumer's risk)** = 0.02
  - **AQL (acceptable quality level)** = 0.01
  - **LTPD (lot tolerance percent defective)** = 0.05

α	0.05
β	0.02
AQL	0.01
LTPD	0.05
Lot Size	1000

Figure 26 – Table of parameter in AQL.

Table I—Sample size code letters

(See 9.2 and 9.3)

Lot or batch size			Special inspection levels				General inspection levels		
			S-1	S-2	S-3	S-4	I	II	III
2	to	8	A	A	A	A	A	A	B
9	to	15	A	A	A	A	A	B	C
16	to	25	A	A	B	B	B	C	D
26	to	50	A	B	B	C	C	D	E
51	to	90	B	B	C	C	C	E	F
91	to	150	B	B	C	D	D	F	G
151	to	280	B	C	D	E	E	G	H
281	to	500	B	C	D	E	F	H	J
501	to	1200	C	C	E	F	G	J	K
1201	to	3200	C	D	E	G	H	K	L
3201	to	10000	C	D	F	G	J	L	M
10001	to	35000	C	D	F	H	K	M	N
35001	to	150000	D	E	G	J	L	N	P
150001	to	500000	D	E	G	J	M	P	Q
500001	and	over	D	E	H	K	N	Q	R

Figure 27 – Table of sample size code letter

- **Thus, depending on lot size we must:**
  - **Normal Inspection** = General II
  - **Plan** = J

➢ ***Finding the correct sampling plan using the nomograph***

We decided to use Nomograph with the parameter given to find the starting point for acceptance sampling

- **OC (AQL)** =1-α =0.95
- **OC (LTPD)** = β =0.1
- **LTPD** = 0.05
- **AQL** = 0.01
- **N** = 1000
- **n (Number of Samples to be taken)** = 250
- **C (Number of defects)** = 5

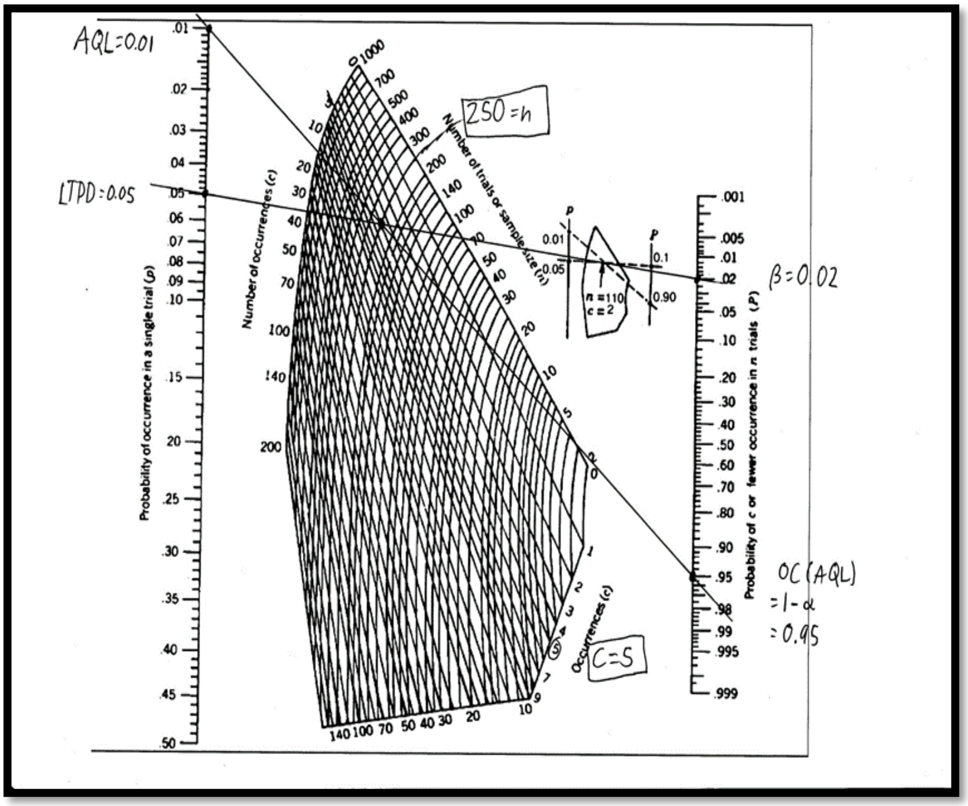


Figure 28 – Nomograph stretch.

- ***Operating Characteristic Curve***

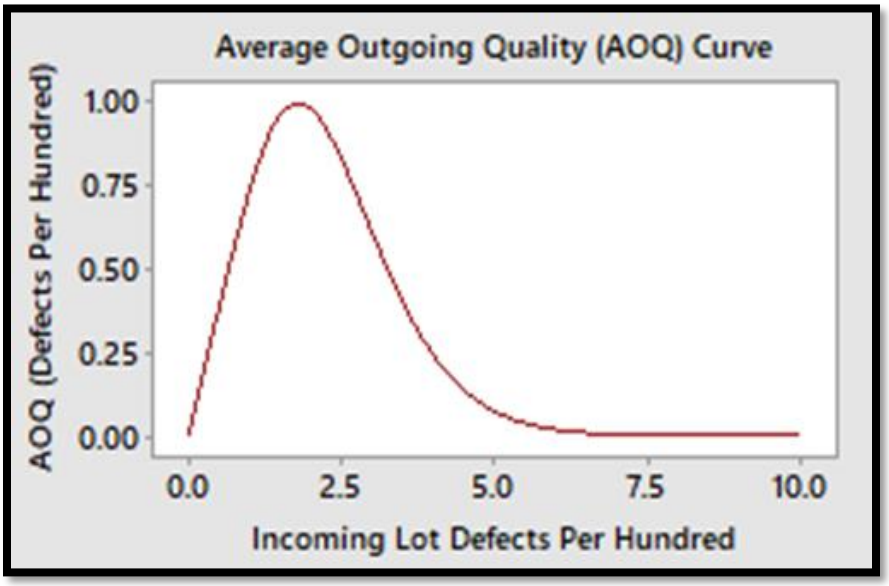


Figure 29 – Operating characteristic curve

Here, we can clearly see that the number of Lot defects per Hundred reaches 2 we get the highest AOQ which is 1.

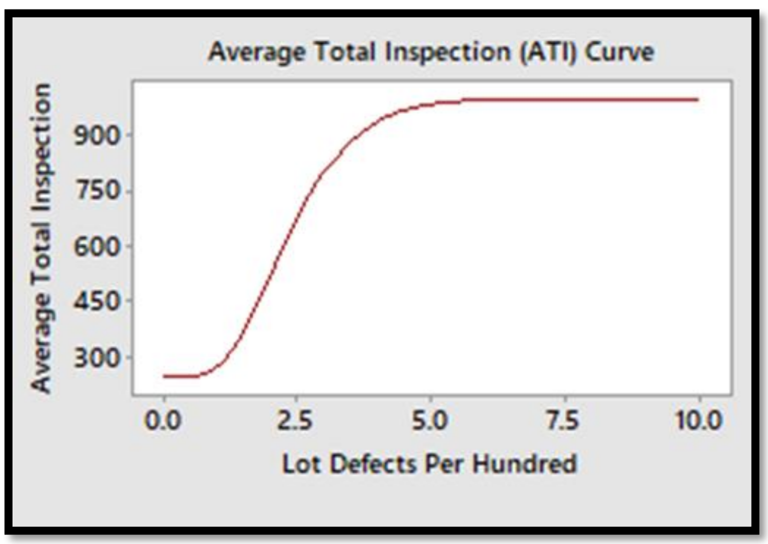


Figure 30 – Average total inspection curve

It's important to note that the average total inspection cost increases sharply from 1 defect lot per hour to 3 defective lots per hour. Thereafter, the graph shows steady maximum cost associated to the process.

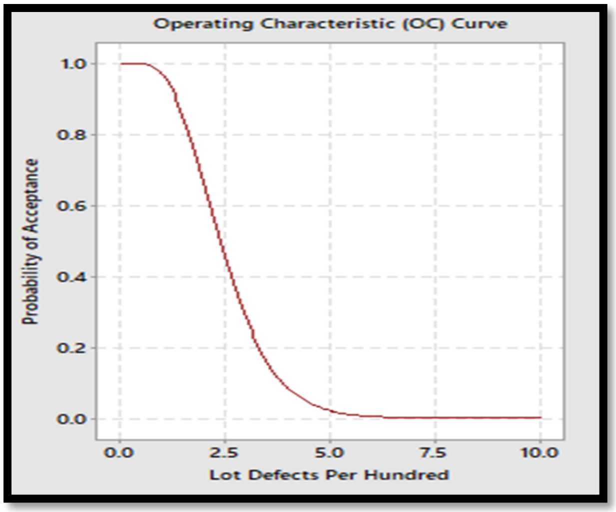


Figure 31 – Operating characteristic curve.

- The operational characteristic (OC) curve displays an acceptance sampling plan's discriminatory capacity.
- The OC curve measures the odds of accepting a lot vs. the proportion of lots that are faulty.
- A chart displaying the likelihood of acceptance vs the percentage of defective items is known as an operational characteristic (OC) curve.
- The use of sampling plans involves risks for both the customer and the vendor.
- We can clearly see above that as probability increases above 3 the likelihood moves to almost 0.

SPC Charts example from data

After the improved process we tried to understand where the increased number of containers will bring our uncontrolled process back to the improved state or not. We used the X-bar chart to examine the range of the number of containers and found the revised plan with the varying demand will keep our process under control. With this good news, we were curious to understand the effect of newly calculated values for cranes too.

$$UCL = \mu + 3\sigma$$

$$LCL = \mu - 3\sigma$$

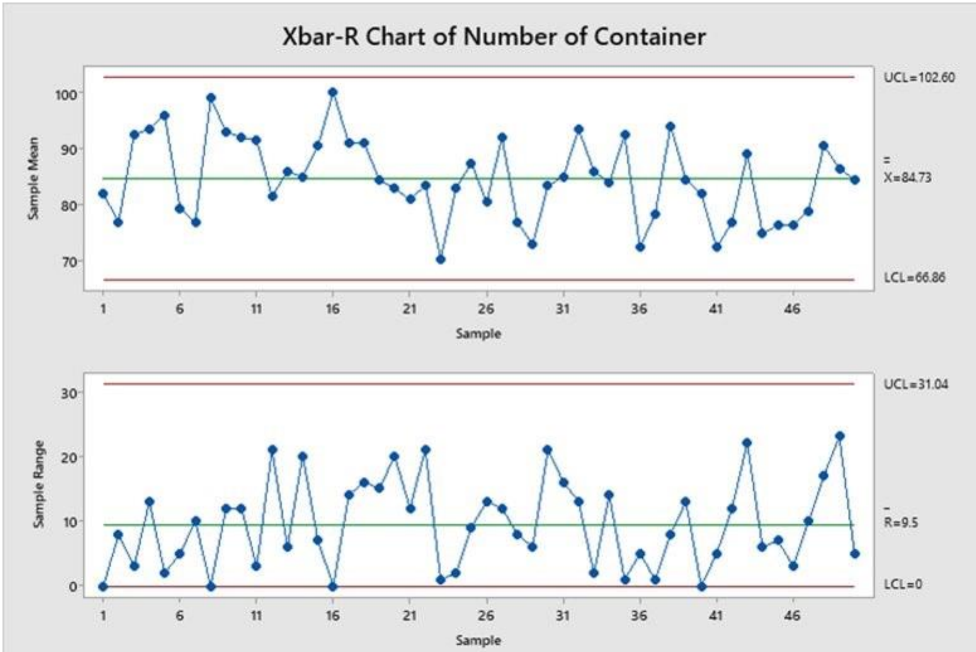


Figure 32 – Xbar-R chart of number of container

After the improved process we tried to understand where the expected number of defective cranes due to downtime expected will result in uncontrolled process. We used the P-chart to examine the effect of containers and found the revised plan with the varying demand will keep our process under control. Thanks to P Chart we will now be able to cope with defects too.

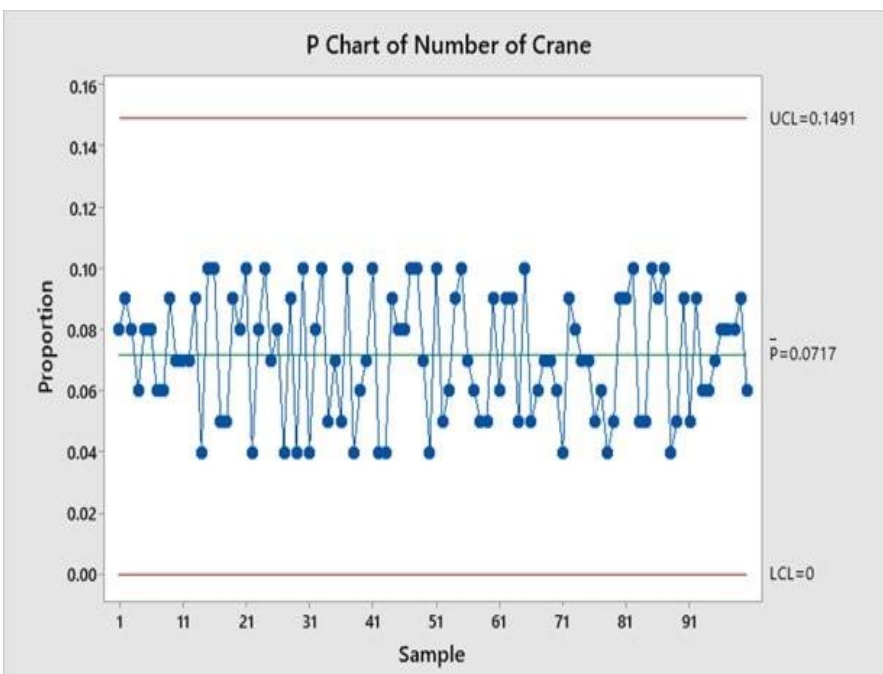


Figure 33 – P chart of number of cranes

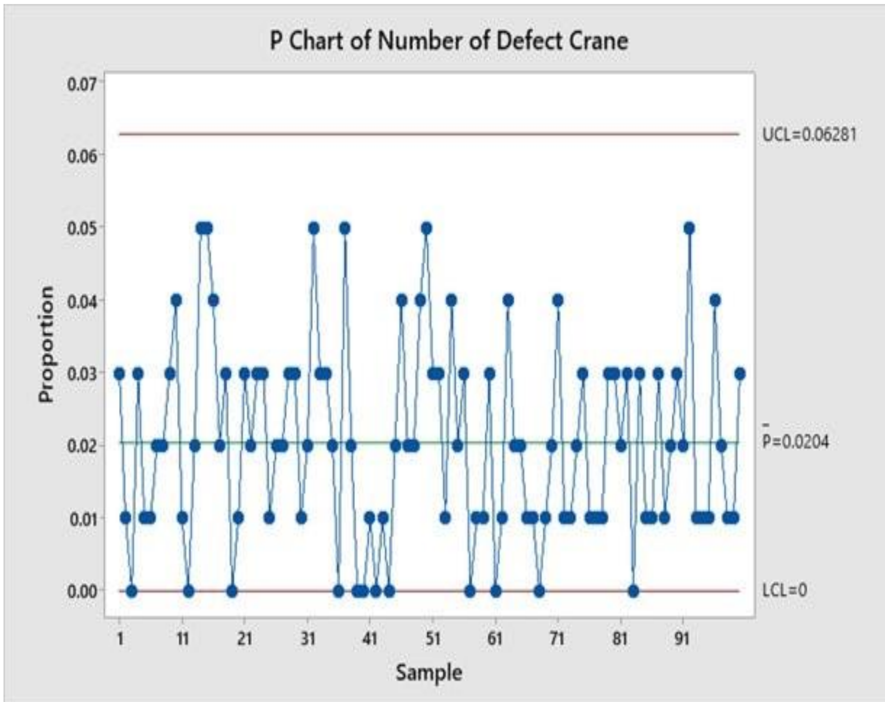


Figure 34 – P chart of number of defect crane.

$$\text{Mean (Target)} = \lambda;\ \text{UCL} = \lambda + 3\sqrt{\lambda};\quad \text{and}$$
$$\text{LCL} = \lambda - 3\sqrt{\lambda}\ (\text{if LCL is} > 0;\ \text{otherwise LCL} = 0)$$

Reliability analysis (FMEA or FTA)

Reliability is defined as the probability that a product or system will operate in a defined environment without failure. However, reliability is a quantification in terms of probability. Also, it's a statement about defining successful product performance and the environment in which the equipment must be operated. The probability of the product and system will fail within a certain range of time. In reliability analysis, there are two different contents FMEA & FTA. FMEA stands for failure model effects analysis which is actions about the risk of failures and will be used in continuous improvement. FTA stands for fault tree analysis and it's a graphical tool to explore the cause of system failure level. In addition, it can be used to identify the component level failure (bottom of the graph) that causes the system level failure (top section) to occur.

Function	Failure Mode	Effects	Severity (10-Most)	Causes	Occurrences (10-Most)	Detection Action	Ease of Detection (10-Lowest Prob)	Risk Priority Number	Recommended Action
Packing & Distrubutions Part 1	Shortage of Container	Multiple shipping for one large product order	8	Increase of ship container demands	7	None	5	280	Pre-order & back up plan
Packing & Distrubutions Part 2	Shortage of Cranes	Extra loading time at port	5	Shortage of Crane operators	6	None	5	150	Hire and train more crane operators
Packing & Distrubutions Part 3	Shortage of Ships	Longer waiting and shipping time for large amount of product	8	Size of ship company	7	Pre-investigation	5	280	Back up shipping company
				Covid	3	None	5	120	Backup plan for uncontrollable factors

Figure 35 – FMEA chart for shipping products

From FMEA analysis, the team focuses on shortening the delivery time to the customer. It will have three different failure modes that are related to the packing & distribution which are shortened of containers, cranes, and ships. In the chart, it shows the severity occurrences, and ease of detection with risk priority to show the risk of each failure mode. For the number of the parameters, 10 represent the most and 1 represents the lowest level. Each of the failure modes has the corresponding effect, detection action and recommended action for the prevention.

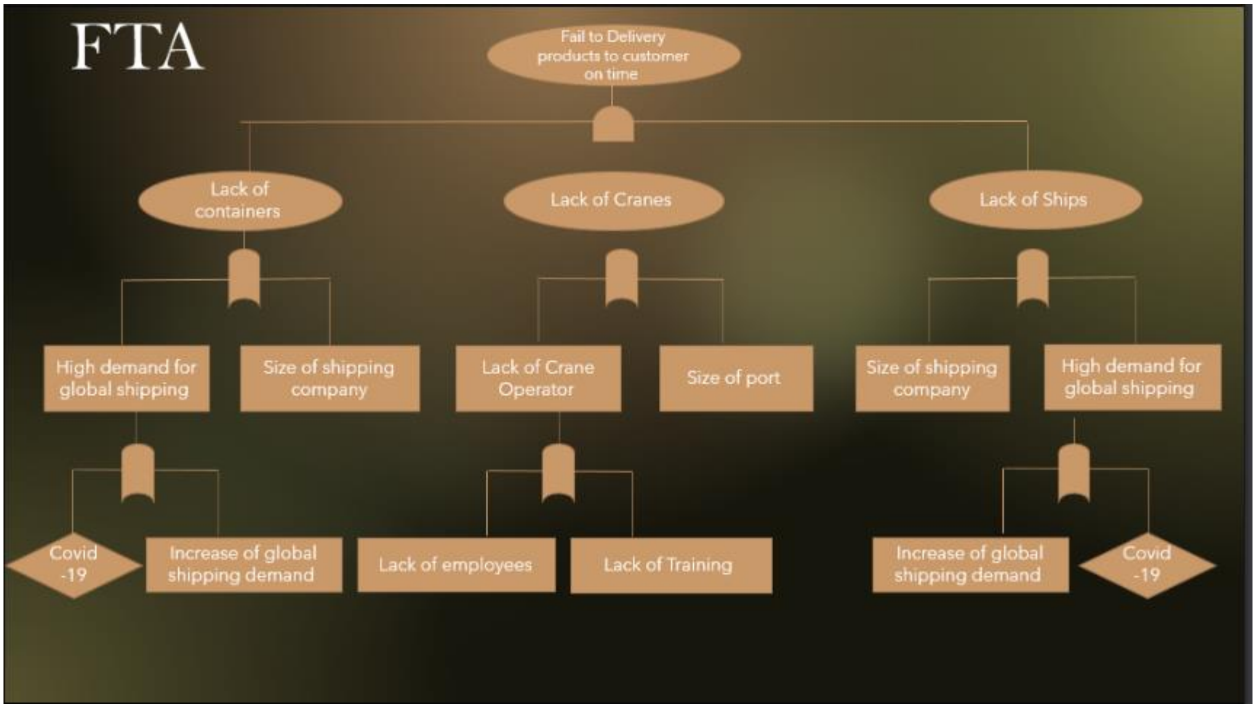


Figure 36 – FTA chart for failing to delivery products to the customer on time.

From the FTA analysis, there are three factors that relate to the failure to deliver products to the customer on time. Since product delivery is very important to the customer, there are a few reasons leading up to the failure which are lack of containers, cranes, and ships from today's world especially under pandemic. The diamond shape represents undevelopment reason and square represents development reason. In the FTA analysis, the team can determine the priority to solve the potential dangers for delivering the products to the customers.

The failure rate is a parameter that refers to how often the supply chain system will lead to late delivery. However, the mean time to failure (MTTF) is maintenance metric that measures the average amount of time in a non-repairable asset operates before its failure. For the reliability analysis, the team used 95% confidence intervals to find the reliability probability to check it's based on the mission time. So, the team sets the MTTF to 1500 days for supply chain will lead to late delivery of the products to the customer. The mission time of 500 days for the supply chain and the reliability has lower and upper bound with 41% and 73% respectively.

	Complete	Truncated 3rd Failure	Truncated at T = 500 days
95% CI for MTTR	(856.431 , 2396.374)	(584.20 , 6807.85)	(855.676 , 6880.734)
95% CI for FR	(0.000417 , 0.001168)	(0.000147 , 0.001712)	(0.000145 , 0.001169)
95% CI for reliability at Mission time = 500 days	(0.4165 , 0.7312)	(0.2769 , 0.8957)	(0.4162 , 0.8967)

Figure 37 – Result of MTTR, FR, and reliability for mission time = 500 days

Conclusions

From DOE Analysis we conclude:

- All three factors are significant to the problem. Working on them will help us reach our target.
- The interactions aren't significant except for the interaction of AB. However, it doesn't have much impact on the project.
- It's important to note that the value of ABC has a negative co-efficient thus we must be circumspect while increasing the values of the factors.
- To reduce the lead time, we should have an increased number of ships, cranes as well as containers.
- From FMEA & FTA analysis
- For a fixed set of number of containers, cranes, and shipping company in the supply chain, the reliability was calculated to determine the sense of trust for the supply chain.
- Use mission time to track the reliability of the supply chain system
- FMEA analysis the causes & effect and potential solution to increase the reliability of the system
- FTA gives the failure for each component that led to failure of delivery the product on time.
- From SPC charts
- The variables and attribute charts were plotted for the data set until a shift in mean or an abnormal condition was detected. The team observed that the warning limits predict a trend and can be used to stall a process before it becomes unstable.

The direct impact including:

- Quality affects every process.
- Quality affects profits and market share.
- Quality issues are often unnoticed.
- Quality assessments uncover the impact.
- Quality methodology solves the impact.
- Quality improvements pays for the impact.

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