Development of Supply Chain, Quality Control, and Safety By Implementing Industrial Engineering Concepts: A Paint Factory Case-Study

Development of Supply Chain, Quality Control, and Safety By Implementing Industrial Engineering Concepts: A Paint Factory Case-Study

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ABSTRACT

This report examines the relationships and contributions of multiple industrial engineering fields in the development process of a paint factory facility located in Zarqa/Jordan. The main aim of this report is to study the effect of applying industrial engineering concepts with a developmental approach in order to achieve the highest level of performance with the least waste possible. The report represents a full documentation and discussion of the process followed in the project and its outcomes.

ACKNOWLEDGEMENTS

Thanks are due to everyone who contributed in the process towards this project,

To our supervisor, Professor Abdullah Al-Dwairi for his guidance and advision throughout the project.

To all the professors and tutors who helped us build the concepts over which the whole project was based on.

To our families and friends who stayed supportive all the way until the end.

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1. Introduction

The subject of this case study is a paint factory that belongs to Fixtone Paints. The factory is located in Zarqa governorate in Jordan and has been operating from there for 10 years. Covering an area of 2647 meter-square, the factory consists of a managing department, a laboratory, the production line, and four inventory storages. The main products of the factory are water-based and solvent-based paints in addition to putty, raw materials and other products.

However, the factory was found to be lacking a development department, a quality control policy and development plan. Moreover, the manufacturing and production processes management relies on basic and abstract managerial concepts which aren't highly efficient. The factory uses a pull system of production and relies on the market demand for its production but at the same time has seasonal and safety inventory in order to fulfill its distributors demand.

This case-study aims to improve the supply chain, quality control, and safety aspects of the factory in a developmental approach by studying every aspect and investigating the factory case further. Using various statistical and mathematical methods, the data collected from the factory goes through an analysis and development phase followed by a discussion of the analysis outcomes before translating them into improvements and solutions. These improvements were then rephrased into recommendations that were handed to the factory management for evaluation and possible application.

To sum it all up, this report represents a step by step process in which the improvements in the supply chain, quality control, and safety were developed for Fixtone Paints company's factory based on a scientific approach and using industrial engineering concepts in order to improve the efficiency and productivity of the factory and it’s production line.

1.1 Problem

At first sight, the factory seemed to be running very efficiently, the production lines were all running, and no idle machines nor queued containers were found; this led to a very good first impression regarding the level of productivity and utilization of the factory.

However, when studying such cases, first impressions and random observations can't provide accurate measurements or resolutions; it's the data and metrics of performance that should be taken into consideration instead. By referring to the managing departments and collecting data from various sources, the values for the performance metrics, which were then standardized, came to give a very different and more detailed insight into the real problems that were facing the factory on various levels and in multiple aspects of how the factory runs.

On the one hand, the factory runs in a very practical and efficient way regarding the production processes. No major issues or surfacing problems were present. The lab inside the factory prepares samples of paint which are tested for viscosity using a Krebs Stormer Viscometer, and then the same samples are applied on carton films using an automatic film applicator depending on the base color and then run through the following tests:

1. Hardness Test (West Abrasion Scrub Tester)
2. Weather Wearing Test (UV Light Accelerated Weathering Test Cabinet)
3. Color Reflectivity Test (LED Color Spectrum Cabinet)

The percentage of each material used in the making of the sample and order of mixture "Paint Recipe) remains reserved for each sample. Once approved by the laboratory, the recipe is then sent to the preparation station, where containers are prepared accordingly for the mixture. The factory contains four separate mixers, each with the capacity of 1 ton, 3 of which are used for water-based paint and one for solvent-based paint, two additional mixers each with the processing capacity of 3 tons, and a reservoir with the capacity of 6 tons for each mixer, one is used for emulsion paint and the other for putty. The outcome mix is then poured into containers and transferred into inventory or shipped to customers.

On the other hand, the lack of quality control and assurance alongside the unscientific method used to run the production process and make sure it runs in the optimal and most efficient way all led to a very hard-to-develop structure of processes inside the factory. A good portion of the data had to be collected and calculated manually to make sure the value assigned to the required metrics was as accurate as possible. That's all due to the documentation of the measurements inside the factory being very generic and basic. Despite the factory's management being open to development and very helpful regarding the data, it had to take a lot of time to analyze the given measures and understand the real sources of the problem and categorize them into fields of applied industrial engineering concepts so that they can be further investigated and studied more specifically and accordingly.

As a result, after referring to multiple academic, scientific and applicative industrial engineering resources, these problems and bottlenecks were categorized into three different aspects to further study, investigate and develop in this study:

1. Supply Chain.
2. Quality Control.
3. Safety.

Each of these fields will be further studied in this report as a separate chapter.

1.2 Objective

In what way can supply chain, quality control, and safety management concepts be applied in order to develop a more efficient and productive scheme for the factory to work on.

1.3 Approach

The main aim of this project is to evaluate the performance of the paint factory, analyze it, then apply industrial engineering improvement and development concepts and methods in order to achieve the optimal performance with the highest production and safety standards possible.

After analyzing the data given by the factory, a better evaluation of the current state of the factory and its production line. Once this evaluation is complete, the development phase begins by finding what an optimal state of the factory, with the given fixed values, should look like and what values of multiple metrics it should meet. From there, the issue becomes nothing but pure engineering, a way to tackle problems, the difference between the given and standard value, using multiple solutions techniques and methods.

1.4 Research Constraints and Impact

Having very limited work time for research and due to the close deadline for submission of this report, few aspects had to be picked up from the many over which development and improvement could be performed for the facility, starting with the facility's planning, operations management, quality management & control, supply chain, safety and a lot more.

However, choosing the main aspects and approach for the research was followed by a lot of missing data due to lack of measurements, not to mention the irrelevance and inaccuracy that occurred due to the unscientific approach of management, especially for the main production line.

A lot of the rising issues throughout this research will be further discussed in each chapter depending on the constraints, impacts, and solutions.

1.5 Organization of this Report

Chapter 2 covers the supply chain process towards improvement and development.

Chapter 3 describes the progress and improvements in the quality control sector.

Chapter 4 focuses on the safety issues discovered and solved inside the factory

2. Supply Chain

2.1 Introduction

As a network between the facility and its suppliers that aims to deliver products to customers, a company's supply chain is considered a key aspect for development and improvement with a very direct and surfacing impact on the process.

Multiple elements with variable metrics need to be understood, measured and analyzed in order to evaluate the status of a supply chain and to determine where bottlenecks and errors exist or might occur. These elements include:

1. Facility.
2. Inventory.
3. Sourcing.
4. Information.
5. Transportation.
6. Pricing.

Under each of these elements are multiple and variable metrics that need to be measured in order to evaluate the performance and efficiency of the supply chain for the factory, a lot of these metrics were provided by the factory management staff, and some had to be measured while under research based on the current state of the factory and historical data that was provided by the management. All the metrics of performance for each aspect of the supply chain evaluation were selected based on evaluation criterias and calculations that followed a scientific method in order to set standards based on the given fixed values and to find out unknown values for certain metrics for the case of study.

2.1.1 Process Concept

The process in which the supply chain for any facility can be developed and improved requires evaluation of the current state of the supply chain, and thus it had to be broken down into the supply chain's main elements and then carry an evaluation process using data that has to be either collected directly from the company if ready or measured by calculation using supply chain theories.

Once the data has been collected, the evaluation process begins with a standardization process for each and every metric of performance that has been listed and then uses comparison and differential methods in order to solve any difference between the given and the standard values in an optimization process that converges towards closing that difference with regard to the other values that can be affected by adjusting the certain value.

The main rising issues that face this process occurred in the data collection process due to the lack of data records in the company and depending mostly on basic assumptions and approximations. In order to resolve this issue, various calculations and measurements have been carried out inside the facility in order to attain a higher accuracy of measurement and a more precise value of metrics.

In the end, the whole process comes to the development and improvement phase, which is the main approach of evaluation and analysis. These improvements are all based on a very deep analysis of each metric for every element of the supply chain and are expected to result in an optimized supply chain for the facility in which efficiency of production and level of service becomes balanced with costs and quality of each product. Those improvements were rephrased into recommendations that were handed over to the facility's managing department with full justification and explanations for each term.

2.1.2 Analysis Method

Data analysis can be carried out in various methods using different tools and modules. All of these methods share the baseline of relying on a comparison of the given data to some standard that is set differently in most methods. Due to this difference, these methods vary in accuracy of comparison and outputs.

However, in this case study, the method that was found to be most practical was a cross between meta and thematic analysis. Each metric was standardized using mathematical and statistical tools and equations in order to achieve an optimal standard for each metric. The given value for each metric is compared to the standard value for the same metric. For comparison, various methods were followed, such as charts, histograms, subtraction, and interpolation, in order to attain an accurate comparison.

In addition, factors that affect each metric were listed next to the standard value to refer to when optimizing and to adjust the given values to converge towards the standard value. This process has been carried on by referring mainly to the equations used to calculate the value and listing the variables included in each equation, other methods such as policies and articles about each metric. These factors also came in handy as they developed a better perspective of how the adjusting of any value using a certain factor that affects it might reflect a change in the value for another metric in the case of shared factors between both metrics.

As a result, the analysis method used came through as a practical way of sorting out metrics of performance and the weight of each metric on the facility's general performance and productivity level. With the data finally being analyzed and prepared for discussion and improvement, this process created a very totalitarian vision for the improvement and development phase to be carried out.

2.2 Data Collection and Evaluation

With this step being the baseline of the whole supply chain improvement and development process, the data collection phase had to be executed in the most accurate and precise way in order to attain the same level of accuracy in the following phases. In order to achieve this level of accuracy, the data was mostly recalculated over multiple iterations with a very low margin of error. Multiple values for different metrics were calculated over more than three site visits in order to avoid instantaneous events occurrence and errors. Other values were calculated with reference to historical records from the facility, some of which were directly ready to list in the tables prepared for each element.

As a result, after setting the performance metrics for each element of the supply chain and calculating the current/given value for the facility, in addition to setting the standard value that should be met by it. The final tables for each element were as the following:

2.2.1 Facility

Performance Metric	Given Value	Standard Value	Factors
Capacity	2647 m^2		
Utilization	20-25%	Less than 30%	Capacity Flow rate
Process/Setup/Idle Time	30 min/ton	null/ seek decrease	
Average Production Cost Per Unit	15000 per ton		
Quality losses	15% (for solvent-based paints)	Around zero	Idle Time Processing Time
Theoretical flow /Cycle Time	1–1.5 hrs	N/A	Active Time
Actual Average flow/ Cycle Time	1.25 hrs	N/A	Active Time
Flow time efficiency	75%	85%	Active Time /Total Time
Product Variety	Water-based/Solvent-based	N/A	Customer Demand
Volume Contribution of 20% of SKUs	More than 80%	80%	Cost Volume Profit
Average Production batch size	1.5 ton	N/A	Customer Demand
Production Service level	80%		

Table (1) Comparison between given and standard values for facility performance metrics

After using comparative meta-thematic analysis and after setting criteria to weight the metrics against each other, with respect to shared factors between metrics and the margin of difference, the main aspect of development to work on for the facility element is quality losses due to the large difference from the standard value that converges towards zero in the optimal case.

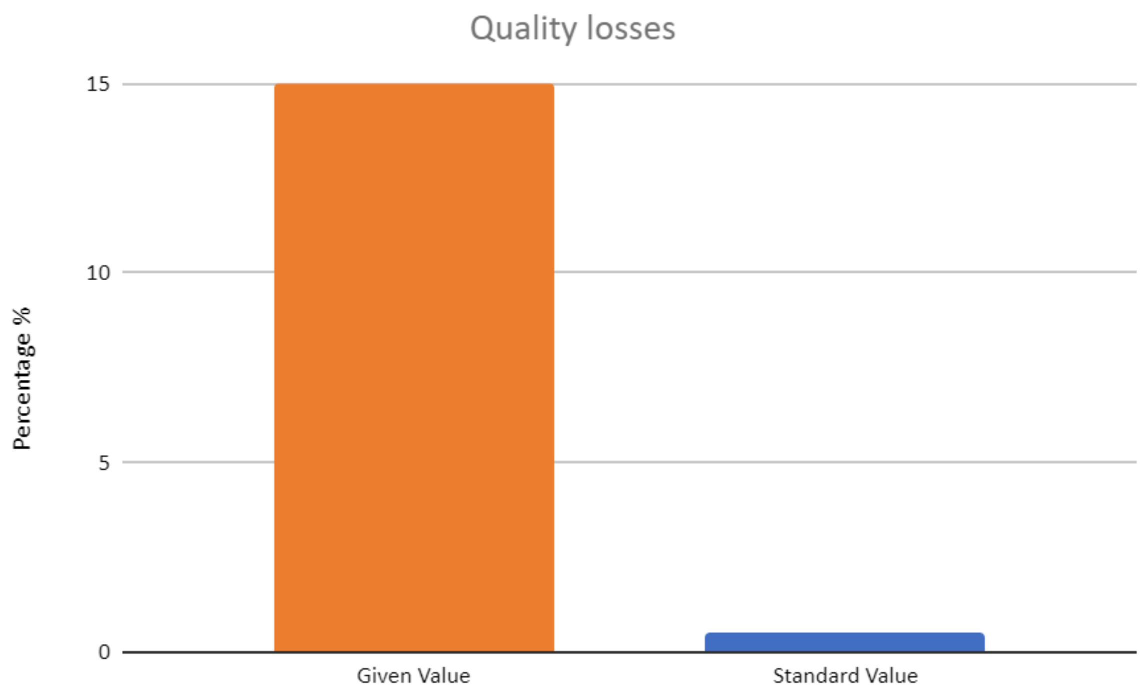


Figure (1) Difference between the given and the standard value of average quality losses

The figure above is a histogram that represents the difference between the given and standard values for the quality losses in the product during the whole production process. The factors affecting this value can be summarized to:

1. Thermal factors.
2. Chemical factors.

In order to estimate the degree of effect of these factors, each factor has to be further investigated and reflected on the given case.

2.2.1.1 Thermal Factors

As a mixture of various particles, paint is affected by temperature directly. The temperature of the air surrounding the paint will eventually turn into either an increase or a decrease in the paint temperature, which in case of an increase will result in the paint wet particles being more active, which will result in thinning the coating and speeding up the drying process. A decrease in temperature, on the other hand, will result in the particles huddling and becoming less active. The resulting outcome of such a decrease will be a very thick texture of the paint, causing it to form wrinkles on the surface and slowing down the drying process of the paint once used.

However, In order to achieve the best results, paint should be manufactured and stored in the “Goldilocks” temperature zone. Note that this range varies slightly depending on the type of paint. Generally speaking, most oil-based paints should be produced and stored in temperatures between 4.4 and 32.2 degrees Celsius, and latex or acrylic paints should be produced and stored in temperatures between 10 and 31 degrees Celsius.

2.2.1.2 Chemical Factors

Paints contain prime pigments to impart color and opacity, binder or resin, which is a polymer forming a matrix to hold the pigment in place, in addition to extenders which are large pigment particles added to improve adhesion, strengthen the film and save the binder.

These compounds are mixed together using specified mixers that assure a homogenous mixture between all of them. In order to achieve this kind of mixture, the mixer blades and core are made from materials that don't react or interfere with the reaction between any of the compounds. Such materials include zinc oxides, titanium dioxides, and stainless steel.

On a side note, solvent-based paints require higher standards of mixers in order to achieve a homogenous mixture. High pressure, fixed temperature, and high friction between paint particles. These standards are met by using customized mixtures that are sealed tightly and then pressurized to the optimal pressure. The mixing blades are replaced with a container of micro glass particles that contains a two-sided valve through which the paint compounds keep running. The micro-glass particles fulfill the friction between particles required.

2.2.2 Inventory

Performance Metric	**Given Value**	**Standard Value**	**Factors**
C2C Cycle Time	Three months for ready gallons Six months for an empty gallon	Four months Six months	
Average Inventory	727 m^2		
Inventory Turns	4	6	
Average Replenishment Batch Size	9 ton		
Average Safety Inventory	40%	43%	
Seasonal Inventory	Summer: 75% Winter: 25%	Summer: 108% Winter: 58.3%	
Fill Rate	92%	90-95%	
Fraction of time out of stock	Two years		

Table (2) Comparison between given and standard values for inventory performance metrics

As it can be concluded from Table (2), the significant difference in values of metrics is present in both safety inventory and seasonal inventory for products. These two terms vary from each other no matter how alike they might seem. Safety inventory is the percentage of inventory from the total inventory that is used to prevent an out-of-stock situation. Meanwhile, seasonal inventory is the percentage of total inventory that is kept at the beginning of each season in order to cover up for the increase or decrease in the demand.

The following figures represent a better observation of the difference between the given values and standard values for each of these two terms.

2.2.2.1 Seasonal Inventory

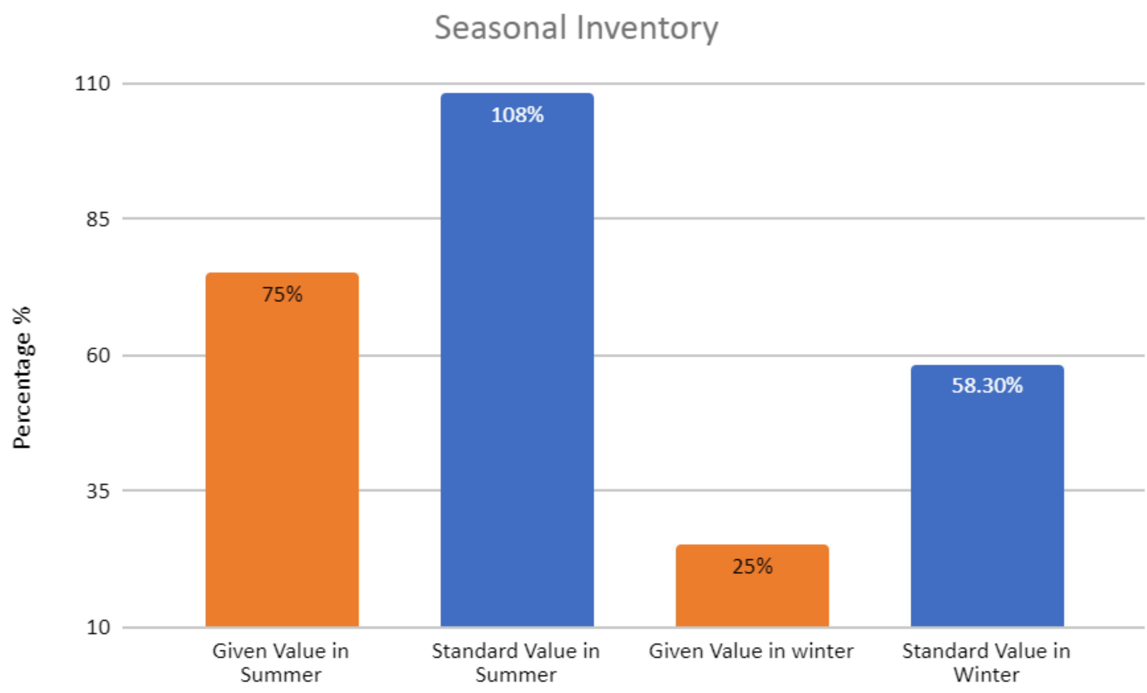


Figure (2) Difference between the given and the standard value of average seasonal inventory

Seasonal inventory for paint factories changes over two main seasons, summer and winter. In this case study, the paint factory sets 75% extra inventory for the summer season and 25% extra inventory for the winter season. This change comes due to the change in demand over seasons. The standard values in this are theoretical and might be inapplicable due to the variance in demand. The seasonal inventory is determined by identifying periods where demand for a product is not synchronized with stocks level, followed by studying sales trends for the past few years and identifying the paint seasonality when demand is at its highest.

However, according to the factory feedback, the percentage of the total inventory used as seasonal inventory being 75% for summer and 25% for winter comes as a result of multiple annual analyses and currently fits the seasonal variance in demand, thus needs no adjusting, however, the study of the sales trends and demand variance will be considered.

2.2.2.2 Safety Inventory

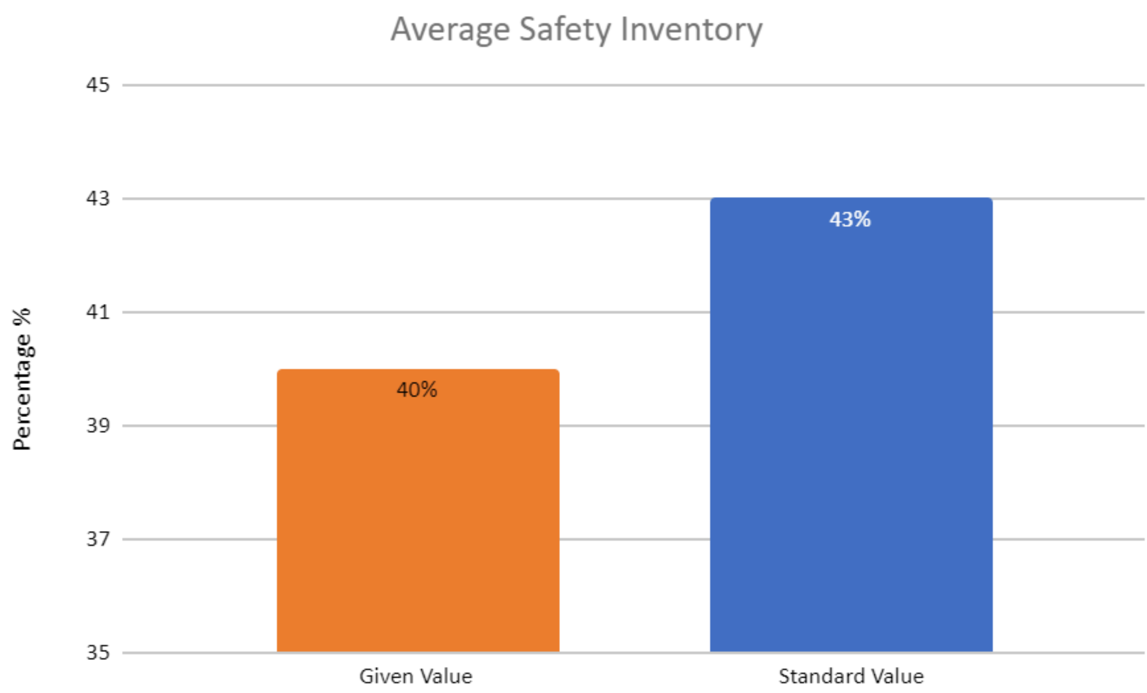


Figure (3) Difference between given and standard values of safety inventory

The safety inventory's main purpose is to prevent any product from an " out of stock" situation that might occur by keeping a portion of "ready for use" products in inventory in case of an unusual increase in demand or shortage in raw material that might occur at any point.

For the standard value, the exact percentage of the portion from total inventory was calculated using the safety inventory equation:

*Safety inventory =(Max. daily use * Max. lead time)-(Avg. daily use * Avg. lead time)*

The resulting safety inventory percentage from total inventory after replacing the variables of daily use and lead time, both in maximum and average, was 43% of total inventory. On the other hand, the safety inventory percentage from the total factory, when calculated manually by the area covered by the total inventory, is 40% which leaves a span of 3% to be used.

2.2.3 Transportation

Performance Metric	Given Value	Standard Value	Factors
Average inbound transportation cost	zero		
Average inbound shipment size	17-20 Ton		
Average inbound transportation cost per shipment	zero		
Average outbound transportation cost	Local: 3% International: 10%	16%	
Average outbound shipment size	Local: 15 ton/month International: 9 ton/month		
Average outbound transportation cost per shipment	Local: 120 International: 520		
Fraction transported by mode	100% by Trucks		

Table (3) Comparison between given and standard values of transportation metrics

Transportation is a variable element in the supply chain that depends on demand, batch size, and a lot of other factors. The standardization step can't be carried out, but further analysis of the case can be carried out with transportation as an indicator for the productivity, demand, and cost analysis for the facility.

For example, as shown in Figures (4) -(6) below, the difference between international and local shipments and their costs can be recognized. Although the outbound shipment size for local shipments has a greater value, the monthly cost of an international shipment is more significant than that of the local shipments.

However, the transportation element is very variable depending on the case being studied and can only come in handy in further analysis of the costs and pricing of production and products, respectively.

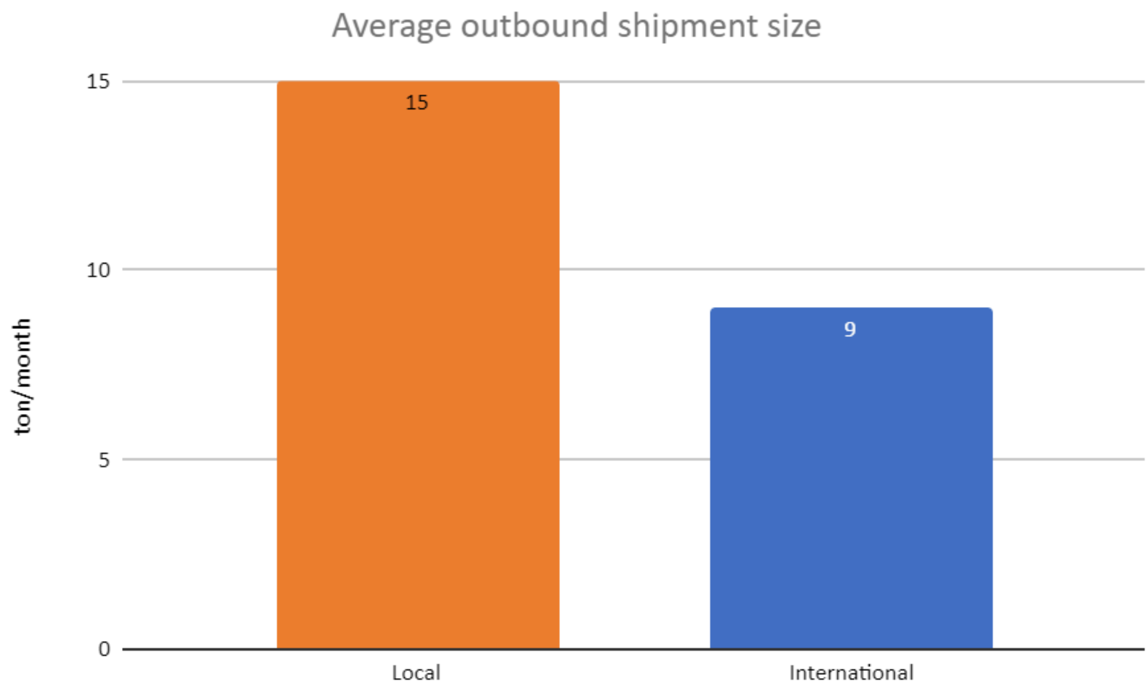


Figure (4) Difference between local and international avg. outbound shipment size

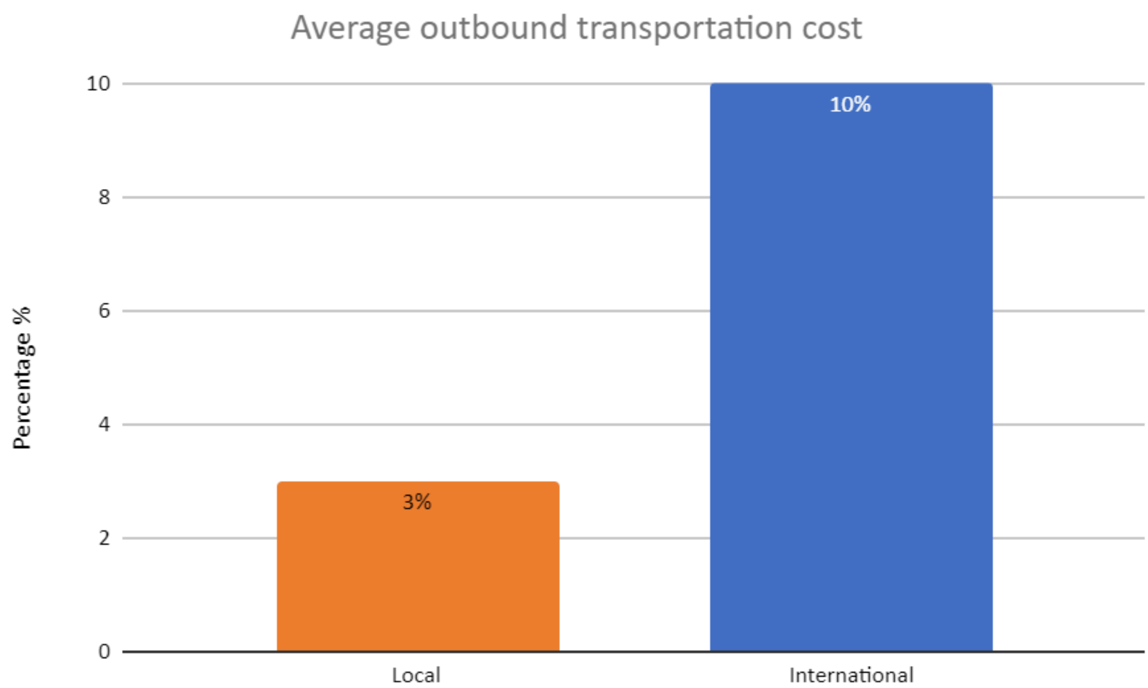


Figure (5) Difference between local and international avg. outbound transportation cost

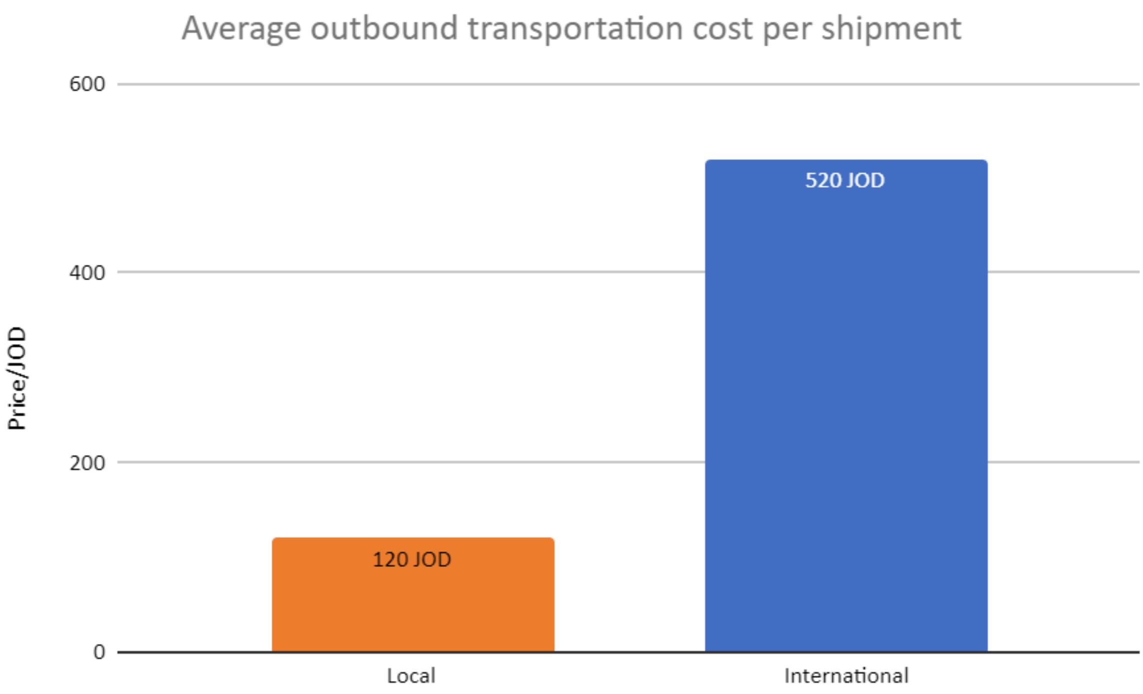


Figure (6) Difference between local and international outbound transportation cost/shipment

2.2.4 Pricing

Performance Metric	Given Value	Standard Value	Factors
Profit Margin	8-10%	8-12%	1)Quantitative factors: Sales earnings Merchandise costs inventory Taxes 2)Qualitative factors: Market share Effective advertising Seasonal changes Sales reward programs Training programs for employees Competition's strength
Days sales outstanding	Daily	36 Days	Non Effective days sales outstanding target No clear payment terms Credit risk management
Incremental fixed costs per order	Undetermined	Undetermined	Rental lease Insurance payments Taxes Utilities
Incremental variable cost per order	25-28%	10%	Direct material Direct Labor Commissions Transaction fee
Average sale price	16-18 jod	17 jod	Cost per product Competition Supplies Demand
Average order size	4-5 ton local 40 ton international	3 tons (custom) 5-10 tons (regular)	Price Customization Size of Factory Raw Materials Factory's stock
Range of price	5-20 jod		

Table (4) Comparison between given and standard values of pricing performance metrics

After referring to the accounting department inside the company and collecting direct given values, all the given values were found to be matching the standard values, which were calculated using equations and formulas based on information gathered mainly from the company's accountants and the distributors supplied with its products.

The data was reviewed and recollected multiple times for assurance, and no significant difference between the given and standard values occurred in any of the trials; thus, no further studying of the pricing performance metrics had to be carried out.

2.2.5 Information

Performance Metric	Given Value	Standard Value	Factors
Forecast Horizon	One month	Two month	Historical Data
Frequency of update	For raw materials: Monthly For products: Demand dependant	N/A	
Forecast error	(mostly production upon order)	zero	Actual demand Forecast demand
Seasonal factors	20%	23%	Weather/Season Society trends
Variance from plan	2%	Less than 5%	Earned Value Planned value
The ratio of demand variability to order variability	3:1	5.5:3	Order Size Average demand

Table (5) Comparison between given and standard values of information performance metrics

The only performance metric with a significant variance from the standard value that can be considered for improvement is the seasonal factor, which is due to various factors that cannot be adjusted for all other performance metrics that don't match the standard value that they should meet.

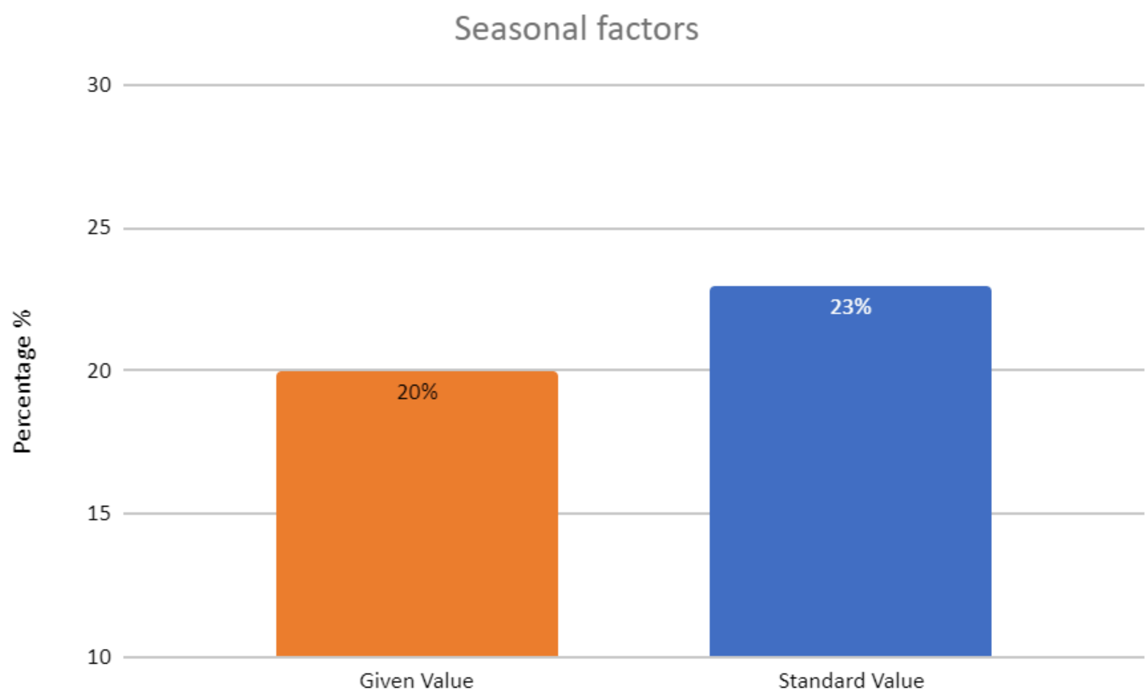


Figure (7) Difference between given and the standard value of seasonal factor performance metric

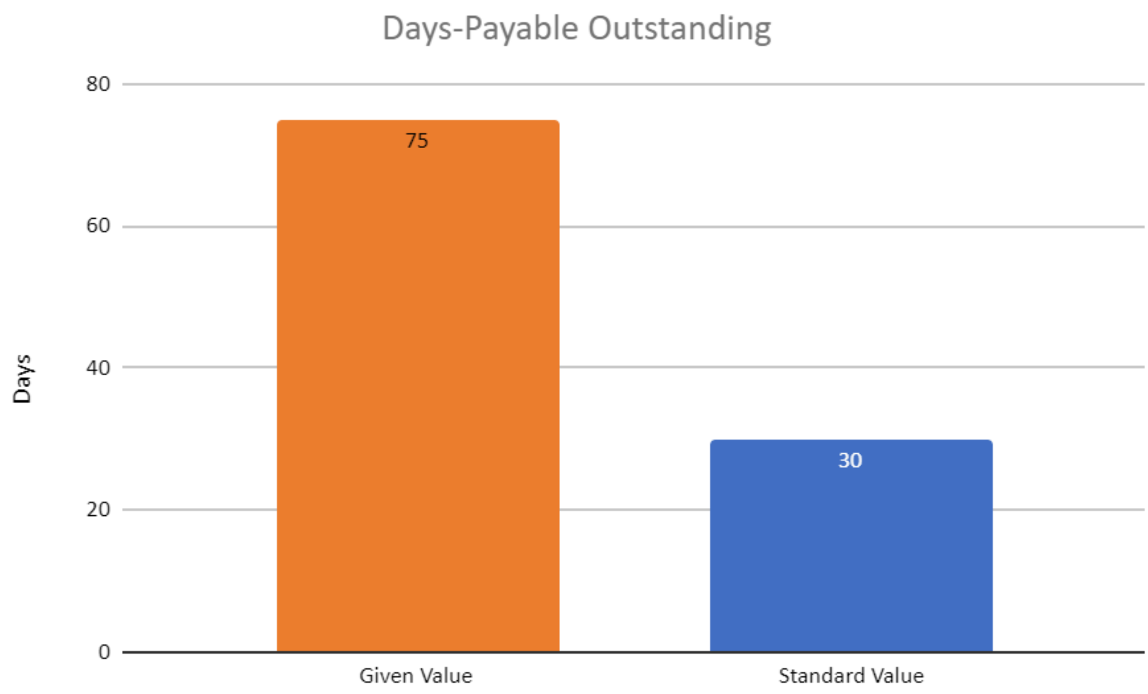
In order to adjust the seasonal factor's value to meet the standard, a time-series analysis had to be carried out to calculate the adjustment value. First, an estimation of the trend by a moving average followed by an elimination of the trend leaving the seasonal and irregular components. Last but not least, an estimation of the seasonal component using the moving averages to smooth out the irregularities will leave us with the adjusted seasonal factor.

2.2.6 Sourcing

Performance Metric	Given Value	Standard Value	Factors
Days-Payable Outstanding	60-90 days	30 days	Competitive positioning of companies
Average Purchase Price	3500	N/A	
Range Of Purchase Price	300-10,000	N/A	
Average Purchase Quantity	120 barrel	N/A	Economic state Functional state
Supply Quality	75%	N/A	Price Location Reliability Lead Time
Supply Lead Time	Within 24 hrs	asap	Stockouts Lead Time Variability Shipping delays
Fraction of on-time deliveries	90%	76-90%	
Supplier reliability	50%	Seeks increase	

Table (6) comparison between given and standard values of sourcing performance metrics

The main aspect to be considered for improvement in the sourcing element of the supply chain is the days payable outstanding as it affects various metrics directly and some indirectly, not to mention how much it affects the pricing element and the company's general financial status.



Figure(8) Difference between given and standard values of days payable outstanding metric

In order to adjust the days payable outstanding, calculations can be adjusted to a quarterly measure by determining the cost of goods sold for the quarter and multiplying by 90 days instead of 365. Similarly, it can also be done monthly by using the monthly cost of goods sold and multiplying by the number of days in the month.

2.3 Improvements and Recommendations

For the final phase of the development process of the supply chain for the factory, the variance of the current values from the standard values of each metric has been analyzed and studied in order to provide a wider range of alternatives and solutions. These alternatives and solutions went through a comparison process that aims to evaluate alternatives and solutions and end up with picking the optimal solution for the case given. The evaluation process is based on efficiency, cost, and applicability.

The first variance issue is the quality loss percentage exceeding the standard value. As mentioned above, paint factories suffer from this issue usually due to two main factors that affect the paint, thermal and chemical factors. In this particular case, the thermal factor is the main cause due to the factory being located in Zarqa, Jordan, and lacking a proper ventilation system. The temperature of the air surrounding the paint mixers in the production line was measured at 39 degrees celsius at its highest and averaged 33.7 degrees celsius on summer days. The average temperature of surrounding air is not supposed to exceed 34.4 degrees celsius.

After evaluating the alternatives and solutions possible, the installation of an interior HVAC that is located near the mixtures in the production line was found to be the optimal solution in this case. The interior HVAC will withdraw air from the inside out through a censored ventilation fan that is very cost-efficient and doesn't require a customized design. This process will lower the average air temperature surrounding the production line by 3-5 degrees Celsius, depending on the sensor calibration.

This solution was approved by the company management, and the installation process took place in May 2022. The size and exact location of the vents were designed by an HVAC systems engineer, and the temperature of the air surrounding the paint mixers measured 33.2 degrees celsius when it measured 38.2 degrees celsius outside the facility.

The other performance metric in which the factory's current value was adjusted to lower the variance between it and the standard value was the days payable outstanding, a metric used in the sourcing element of a supply chain.

Days payable outstanding, or DPO, is an efficiency ratio that measures the number of days a company takes to pay its suppliers. DPO can also be used to compare one company's payment policies to another. Having fewer days of payables on the books than your competitors means they are getting better credit terms from their vendors than you are from yours. If a company is selling something to a customer, they can use that customer's DPO to judge when the customer will pay and thus what payment terms to offer or expect.

In order to adjust the DPO value to the standard value, DPO calculations can be adjusted to a quarterly measure by determining the cost of goods sold for the quarter and multiplying by 90 days instead of 365. Similarly, it can also be done monthly by using the monthly cost of goods sold and multiplying by the number of days in the month.

However, a strategic approach has been followed in order to create a plan in which the days payable outstanding will be lowered from 75 days down to 34 days leaving only four days of variance from the standard value. This strategic plan aims to strengthen corporate cost management through proper budgeting, lowering the fixed costs, and clearly outlining the fixed and variable costs incurred.

The other side of the plan aims to reduce the complexity of accounts payable processing. That is by recognizing any redundancies, bottlenecks, and inefficiencies while mapping out the accounts payable process of the paint company.

In conclusion of the whole process, bottlenecks occurred in the accounts payable process due to the international payments made for suppliers and customers abroad. Other payment methods were suggested, but no feedback has been received from the paint company yet.

To sum it all up, the improvement process of the paint company's supply chain took a strategic optimization approach that aimed to close the variance between the current value of performance metrics for various supply chain elements and the standard value of the same metric. The two metrics that were considered for improvement were the quality losses and the days payable outstanding. An internal HVAC system has been installed, and the effect on paint quality losses was lowered by around 10% as the thermal factor's effect decreased significantly. As for the DPO, days payable outstanding, the sheet of solutions is still under review by the company and awaiting approval.

3. Quality Control

3.1 Introduction and Background

Quality control is the set of procedures that aim to ensure that the quality of the product being manufactured adheres to a defined set of criterias or meets the customer requirements and expectations. In order to achieve this aim, the quality standards set for the production process have to be investigated in detail with the criteria that suit the type of product perfectly.

On the one hand, these criterias are used to measure the quality of production and once followed by a survey that intends to evaluate the quality status of the product based on the main eight criterias of quality evaluation:

1. Performance
2. Reliability
3. Durability
4. Serviceability
5. Aesthetics
6. Features
7. Perceived Quality
8. Conformance to Standards

Once the scaling process for all the criterias mentioned above, a quality flow chart that represents the qualification of a product based on a certain measurement, only then can the product quality be evaluated.

On the other hand, the requirements and expectations of the customers can be measured using a survey that intends to record the score expected for each element of the quality elements discussed above.

Altogether, this process will lead to the improvements that need to be taken into consideration in order to achieve the desired quality that the customer requires or expects. These improvements are each aimed to fulfill an element of quality measurement in the best way that fits the case.

3.1.1 Process Concept

In the paint factory case, the quality control procedures had to be made due to a few observations that indicate a possible lack of synchronization between what the customers require and expect the paint to be and what the factory provides. The quality losses percentage, which has been measured as a performance metric of the facility in the supply chain chapter, was the main indicator over which further studying of the quality case came as a requirement.

However, in order to achieve the quality control improvements desired, a set of procedures has to be followed. These procedures were split into four main phases:

1. Customer's requirements and expectations.
2. The facility provided quality.
3. Analysis and improvements.

Each one of these phases will be further discussed in the following sections.

To sum it up, the process followed was the standard quality control set of procedures followed in order to achieve the required quality standards in the most efficient way possible. The process contained various mathematical and statistical tools and theories such as control charts, flow charts, AHP tools, and multiple industrial engineering theories and measures in order to achieve accurate measurements and optimal solutions and improvements.

3.2 Customer's Requirements and Expectations

Customers' quality requirements and expectations can most efficiently be collected using a survey that indirectly measures all eight quality metrics after setting a scale for each metric. The survey's output of data is then analyzed using various tools that are mainly AHP and then translated into values on the scale set for each metric respectively.

In the paint factory case, the survey was designed to study what customers seek and expect when buying paint in general. This generalization condition comes to make a better understanding of what people look for when buying paint and what weights to assign for each of the metrics/criterias of quality performance for paint in general, and how far the case factory is meeting these metrics/criterias, not to mention the wider sample, the survey can reach out to once generalized. The survey was filled by 232 people, 75.9% of whom were individuals, and the other 24% were paint sellers and retailers. The resulting graphs for some of the questions asked in the survey were as the following:

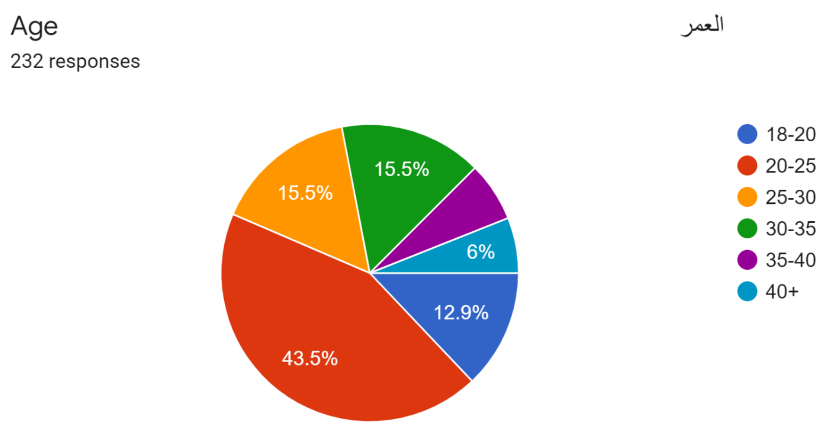


Figure (9) Pie-Chart for age of customers required/expected quality survey

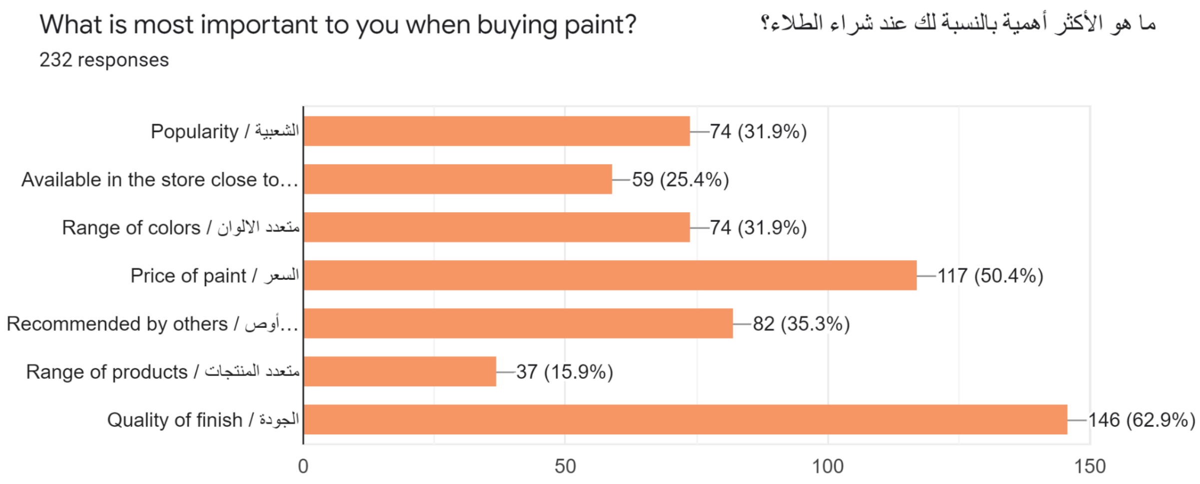


Figure (10) Histogram that shows the most important factors for customers.

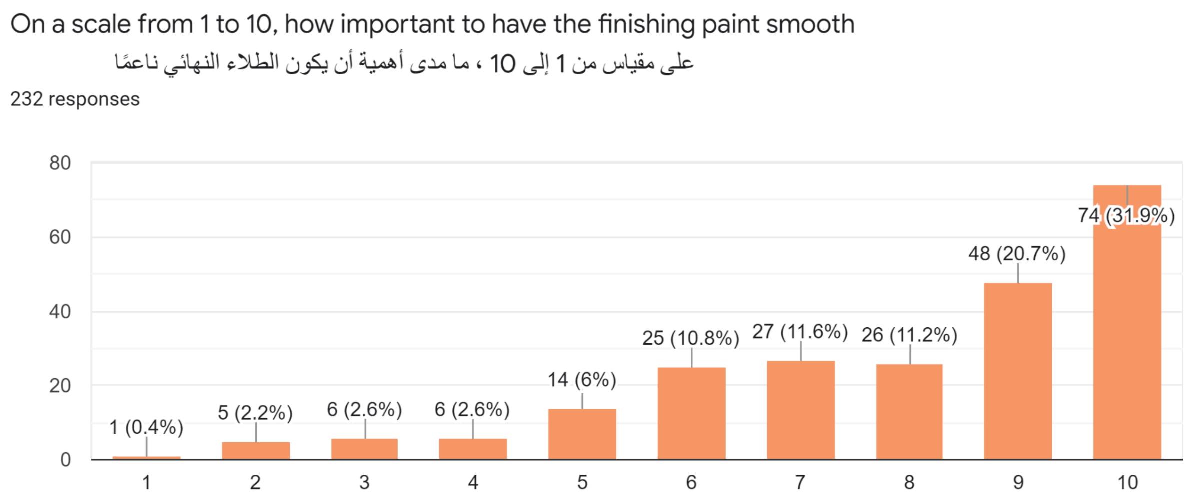
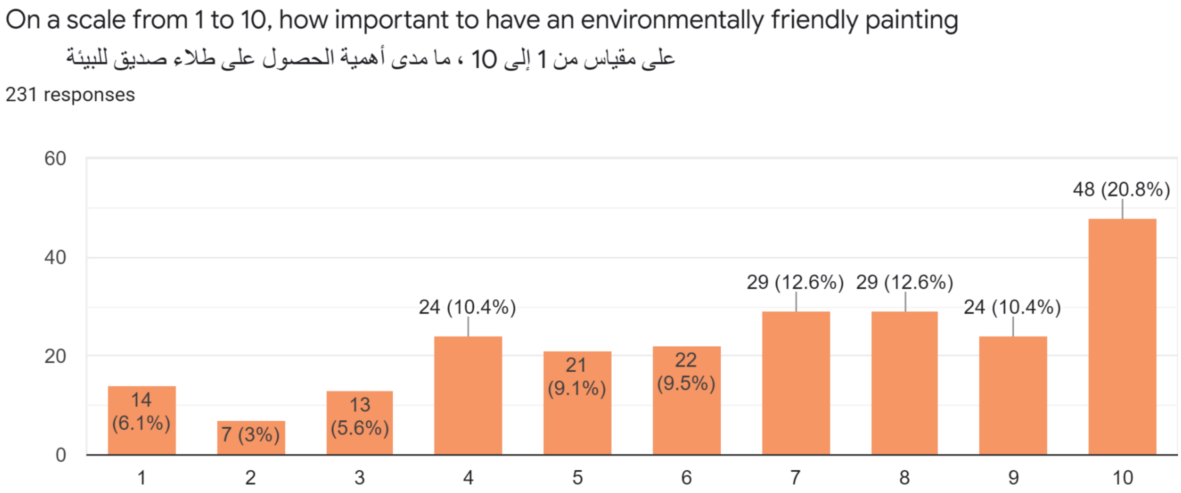
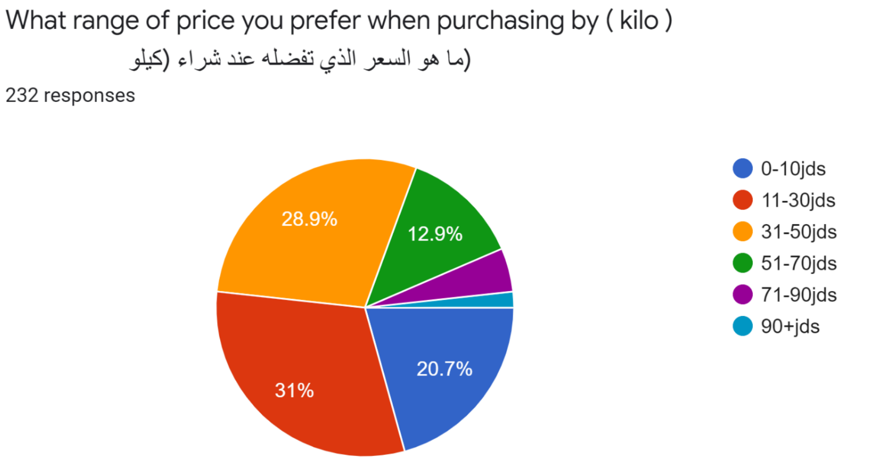


Figure (11) Histogram that shows the importance of paint final finishing for customers.



Figure(12) Histogram of the importance of paint being environmentally friendly for customers



Figure(13) Pie-chart that shows the preferable paint price/ kilo according to customers

The corresponding values for each criterion of quality evaluation listed previously have been estimated using AHP tools in order to weight each criterion and translate the values gathered from the survey into values on a scale from 0 to 10, where 10 is the maximum possible fulfillment of the criteria, in the following are the estimates for these values for each metric/criteria of quality:

Performance:

1	2	3	4	5	6	7	8	9	10

Reliability:

1	2	3	4	5	6	7	8	9	10

Durability:

1	2	3	4	5	6	7	8	9	10

Serviceability:

1	2	3	4	5	6	7	8	9	10

Aesthetics:

1	2	3	4	5	6	7	8	9	10

Features:

1	2	3	4	5	6	7	8	9	10

Perceived Quality:

1	2	3	4	5	6	7	8	9	10

Conformance to Standards:

1	2	3	4	5	6	7	8	9	10

These values over scales represent the quality standards over which customers value the paint they are purchasing. These values are to be compared to the other values in the upcoming sections that are attained by another survey that aims to find where the product of this case lays on each of the scales.

3.3 Facility Provided Quality

Testing for the current quality of any product can be very tricky as the variance in quality differs from one product to the other. This variance can be averaged out by sampling a certain product and then applying the statistical methods to create flow and control charts that will provide a better perspective of the consistency in quality and the margins of error by referring to the upper and lower limits and studying the outliers and their causes.

Paint as a product qualifies mainly on the base of the concentration of solvents. This concentration percentage reflects how durable, reliable, and conforming to standards the paint is. 40% solvent is the concentration the factory sets as the standard for its solvent-based paints. This concentration corresponds very well to the universal standard for the concentration of solvents in solvent-based paints, but that alone isn't enough to assume a good consistency in quality or a match between customer's needs and requirements, and so a flow chart has been developed in order to provide a better comprehension of the situation and what aspect might require improvement and development regarding the factory's provided quality of paint.

In order to study the consistency in the quality of paint, 50 samples were picked randomly and tested for concentration using a kit provided by the factory. These samples were collected in various states and conditions of production on very random instances. Each sample has been tested five times to average out any errors and irregularities in the measurement process.

1	sample	concentration 1 %	concentration2 %	concentration 3 %	concentration 4 %	concentration 5 %	R	X-bar
2	1	39.63	39.68	39.6	39.51	39.62	0.17	39.608
3	2	39.45	39.5	39.52	39.47	39.6	0.15	39.508
4	3	39.84	40	39.91	39.72	39.89	0.28	39.872
5	4	40	39.98	40.14	40	40.07	0.16	40.038
6	5	40.19	40.4	40.23	40.08	39.94	0.46	40.168
7	6	39.8	40.02	39.93	39.63	39.88	0.39	39.852
8	7	40.17	40.04	39.83	39.9	40	0.34	39.988
9	8	39.4	39.59	39.44	39.56	39.61	0.21	39.52
10	9	39.49	39.52	39.67	39.51	39.42	0.25	39.522
11	10	39.91	39.58	39.52	39.42	39.67	0.49	39.62
12	11	40.09	40.21	39.93	39.84	40	0.37	40.014
13	12	40	40.33	40	39.74	39.79	0.59	39.972
14	13	40.19	39.79	39.98	40.8	40	1.01	40.152
15	14	40	39.68	39.88	40.08	39.59	0.49	39.846
16	15	39.96	39.47	40.11	40.35	40.2	0.88	40.018
17	16	39.89	39.74	40.02	40	39.92	0.28	39.914
18	17	40	39.88	39.82	39.74	39.77	0.26	39.842
19	18	40.16	40.06	40.3	39.97	38.87	1.43	39.872
20	19	40.71	38.91	39.79	39.84	40.2	1.8	39.89
21	20	40	39.89	40	40.23	40.12	0.34	40.048
22	21	40	39.79	39.59	40.19	40.06	0.6	39.926
23	22	39.56	39.04	40.2	40.36	39.2	1.32	39.672
24	23	40.03	40.1	39.98	40.06	40.14	0.16	40.062
25	24	39.64	39.61	39.82	39.52	39.42	0.4	39.602
26	25	40.23	40.08	39.83	40.12	40.01	0.4	40.054
27	26	39.81	39.61	39.94	39.62	39.74	0.33	39.744
28	27	39.74	39.58	39.62	39.7	39.68	0.16	39.664
29	28	40.46	40.23	40.45	40.1	40.15	0.36	40.278
30	29	40	39.92	39.69	40.41	40.23	0.72	40.05
31	30	39.4	39.32	39.68	39.6	39.51	0.36	39.502
32	31	39.68	39.5	39.49	39.79	39.83	0.34	39.658
33	32	40.08	40.18	39.88	39.91	40.21	0.33	40.052
34	33	40.12	40.18	40.23	39.88	39.84	0.39	40.05
35	34	40	39.88	40.05	40.18	40.23	0.35	40.068

Table (7) Example from the sampling sheet used to evaluate consistency in quality

As observed in the Table above, the sample was used to develop a control chart that follows the X-R method of control charts, that is, first by calculating the X-bar and R for each sample on its own and then calculating the upper control limit UCL and the lower control limit LCL, then eliminating any outliers that might occur as a result of the process.

$$UCL = \overline{\overline{X}} + A_2\overline{R}$$

$$CL = \overline{\overline{X}} = \sum_{i=1,k} \overline{X}_i \Big/ k$$

$$LCL = \overline{\overline{X}} - A_2\overline{R}$$

1	sample	concentration 1 %	concentration2 %	concentration 3 %	concentration 4 %	concentration 5 %	R	X-bar	UCLr	CLr	LCLr	UCLx	CLx	LCLx
2	1	39.63	39.68	39.6	39.51	39.62	0.17	39.608	0.96779	0.4578	0	40.1618	39.8976	39.6334
3	2	39.45	39.5	39.52	39.47	39.6	0.15	39.508	0.96779	0.4578	0	40.1618	39.8976	39.6334
4	3	39.84	40	39.91	39.72	39.89	0.28	39.872	0.96779	0.4578	0	40.1618	39.8976	39.6334
5	4	40	39.98	40.14	40	40.07	0.16	40.038	0.96779	0.4578	0	40.1618	39.8976	39.6334
6	5	40.19	40.4	40.23	40.08	39.94	0.46	40.168	0.96779	0.4578	0	40.1618	39.8976	39.6334
7	6	39.8	40.02	39.93	39.63	39.88	0.39	39.852	0.96779	0.4578	0	40.1618	39.8976	39.6334
8	7	40.17	40.04	39.83	39.9	40	0.34	39.988	0.96779	0.4578	0	40.1618	39.8976	39.6334
9	8	39.4	39.59	39.44	39.56	39.61	0.21	39.52	0.96779	0.4578	0	40.1618	39.8976	39.6334
10	9	39.49	39.52	39.67	39.51	39.42	0.25	39.522	0.96779	0.4578	0	40.1618	39.8976	39.6334
11	10	39.91	39.58	39.52	39.42	39.67	0.49	39.62	0.96779	0.4578	0	40.1618	39.8976	39.6334
12	11	40.09	40.21	39.93	39.84	40	0.37	40.014	0.96779	0.4578	0	40.1618	39.8976	39.6334
13	12	40	40.33	40	39.74	39.79	0.59	39.972	0.96779	0.4578	0	40.1618	39.8976	39.6334
14	13	40.19	39.79	39.98	40.8	40	1.01	40.152	0.96779	0.4578	0	40.1618	39.8976	39.6334
15	14	40	39.68	39.88	40.08	39.59	0.49	39.846	0.96779	0.4578	0	40.1618	39.8976	39.6334
16	15	39.96	39.47	40.11	40.35	40.2	0.88	40.018	0.96779	0.4578	0	40.1618	39.8976	39.6334
17	16	39.89	39.74	40.02	40	39.92	0.28	39.914	0.96779	0.4578	0	40.1618	39.8976	39.6334
18	17	40	39.88	39.82	39.74	39.77	0.26	39.842	0.96779	0.4578	0	40.1618	39.8976	39.6334
19	18	40.16	40.06	40.3	39.97	38.87	1.43	39.872	0.96779	0.4578	0	40.1618	39.8976	39.6334
20	19	40.71	38.91	39.79	39.84	40.2	1.8	39.89	0.96779	0.4578	0	40.1618	39.8976	39.6334
21	20	40	39.89	40	40.23	40.12	0.34	40.048	0.96779	0.4578	0	40.1618	39.8976	39.6334
22	21	40	39.79	39.59	40.19	40.06	0.6	39.926	0.96779	0.4578	0	40.1618	39.8976	39.6334
23	22	39.56	39.04	40.2	40.36	39.2	1.32	39.672	0.96779	0.4578	0	40.1618	39.8976	39.6334
24	23	40.03	40.1	39.98	40.06	40.14	0.16	40.062	0.96779	0.4578	0	40.1618	39.8976	39.6334
25	24	39.64	39.61	39.82	39.52	39.42	0.4	39.602	0.96779	0.4578	0	40.1618	39.8976	39.6334
26	25	40.23	40.08	39.83	40.12	40.01	0.4	40.054	0.96779	0.4578	0	40.1618	39.8976	39.6334
27	26	39.81	39.61	39.94	39.62	39.74	0.33	39.744	0.96779	0.4578	0	40.1618	39.8976	39.6334
28	27	39.74	39.58	39.62	39.7	39.68	0.16	39.664	0.96779	0.4578	0	40.1618	39.8976	39.6334
29	28	40.46	40.23	40.45	40.1	40.15	0.36	40.278	0.96779	0.4578	0	40.1618	39.8976	39.6334
30	29	40	39.92	39.69	40.41	40.23	0.72	40.05	0.96779	0.4578	0	40.1618	39.8976	39.6334
31	30	39.4	39.32	39.68	39.6	39.51	0.36	39.502	0.96779	0.4578	0	40.1618	39.8976	39.6334
32	31	39.68	39.5	39.49	39.79	39.83	0.34	39.658	0.96779	0.4578	0	40.1618	39.8976	39.6334
33	32	40.08	40.18	39.88	39.91	40.21	0.33	40.052	0.96779	0.4578	0	40.1618	39.8976	39.6334
34	33	40.12	40.18	40.23	39.88	39.84	0.39	40.05	0.96779	0.4578	0	40.1618	39.8976	39.6334
35	34	40	39.88	40.05	40.18	40.23	0.35	40.068	0.96779	0.4578	0	40.1618	39.8976	39.6334

Table (8) Sampling data sheet after calculation of UCL and LCL

Once the upper and lower control limits have been calculated, the sampling data is then ready for translation into a control chart that examines the consistency in quality and how complying with the standard that has been set are the samples. Two charts have been developed, the X bar chart and the R chart, each of these charts has been optimized so that all outliers and human factor errors are eliminated, and the final charts were as the following:

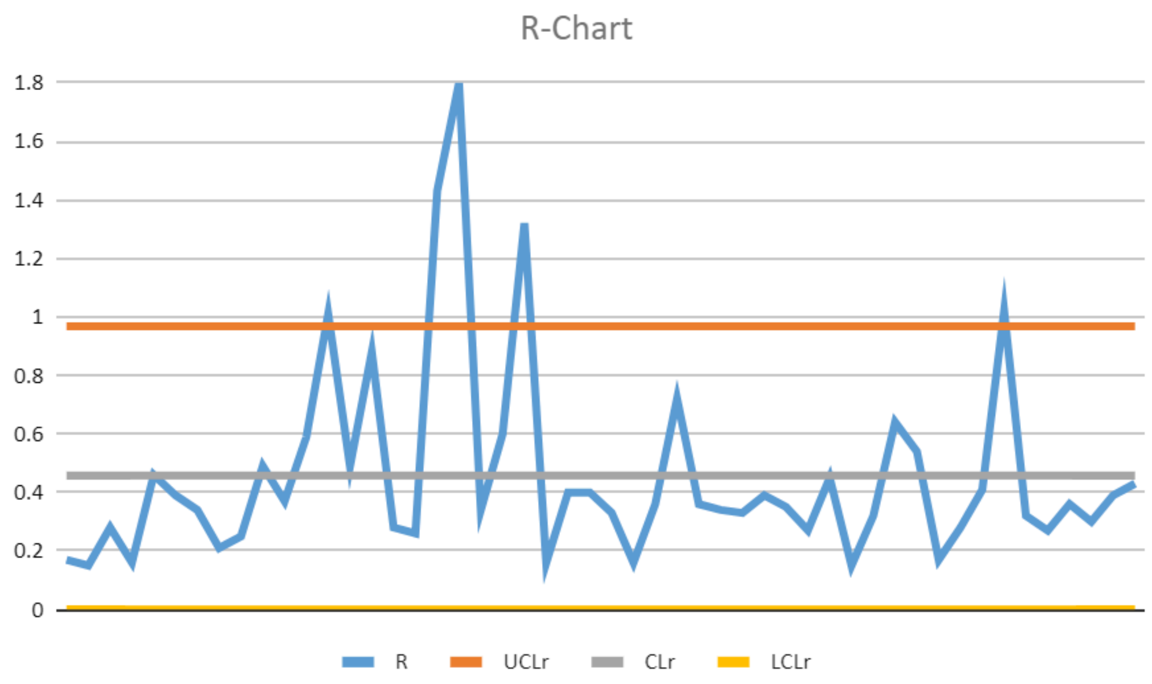


Figure (14) R-Chart for sampling data used to evaluate the consistency in paint concentration.

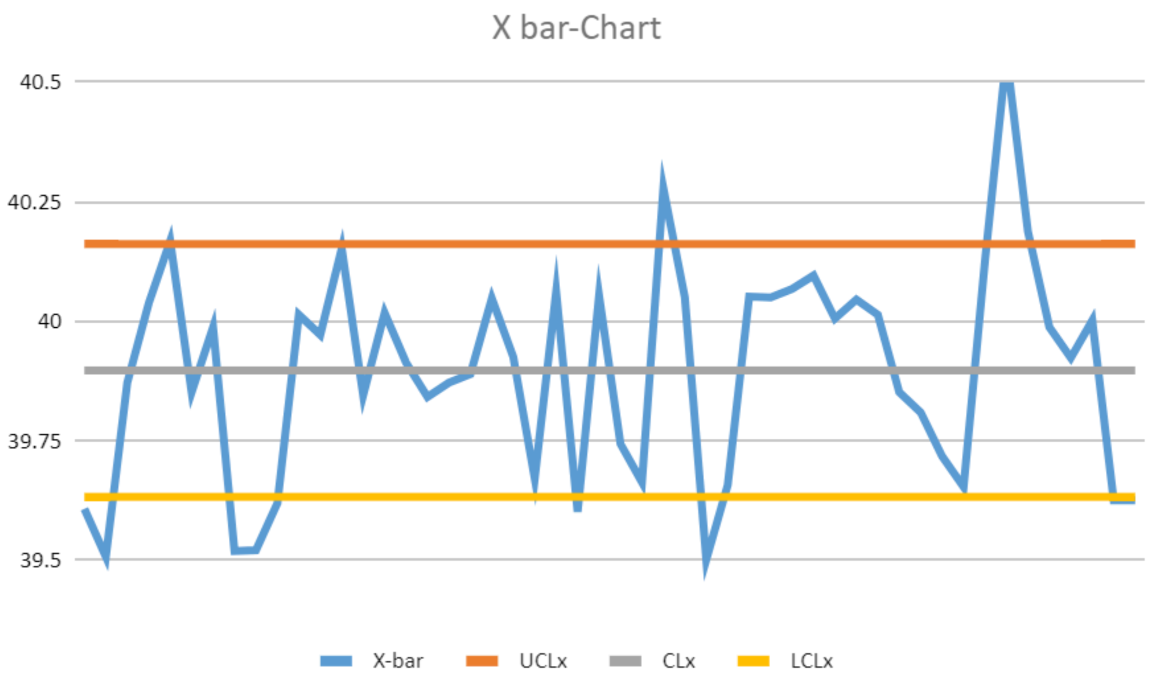


Figure (15) X bar-Chart for sampling data used to evaluate variance in paint concentration.

After referring to the constants for the X-bar and R charts which can be found in Appendix 1, the outliers were all adjusted in order for them to fit between the Upper Control Limit (UCL) and the Lower Control Limit (LCL) of the chart. The resulting values and control charts were as the following:

						Xbar	R
R-bar	0.2528				ucl	26.48986	0.534419
A2	0.577				cl	26.344	0.2528
D3	0				lcl	26.19813	0
D4	2.114						
X-bar	26.344						
					D2=2.326		
					standard	0.196818	

Figure (16) Sheet of adjusted value after referring to the table of constants

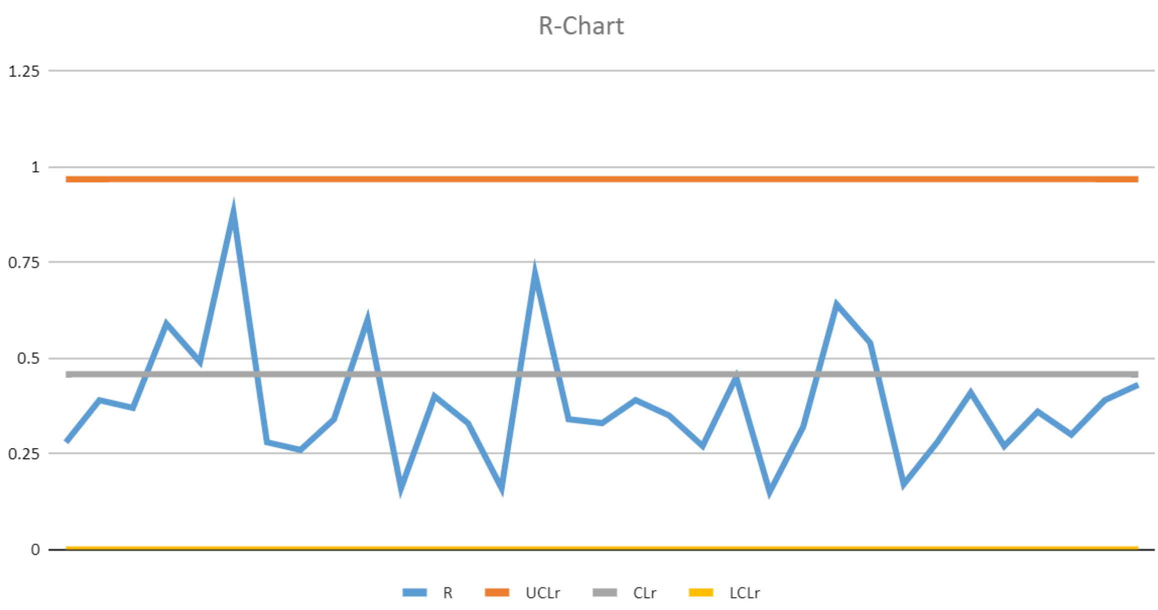


Figure (17) Adjusted R Chart that shows consistency in paint quality

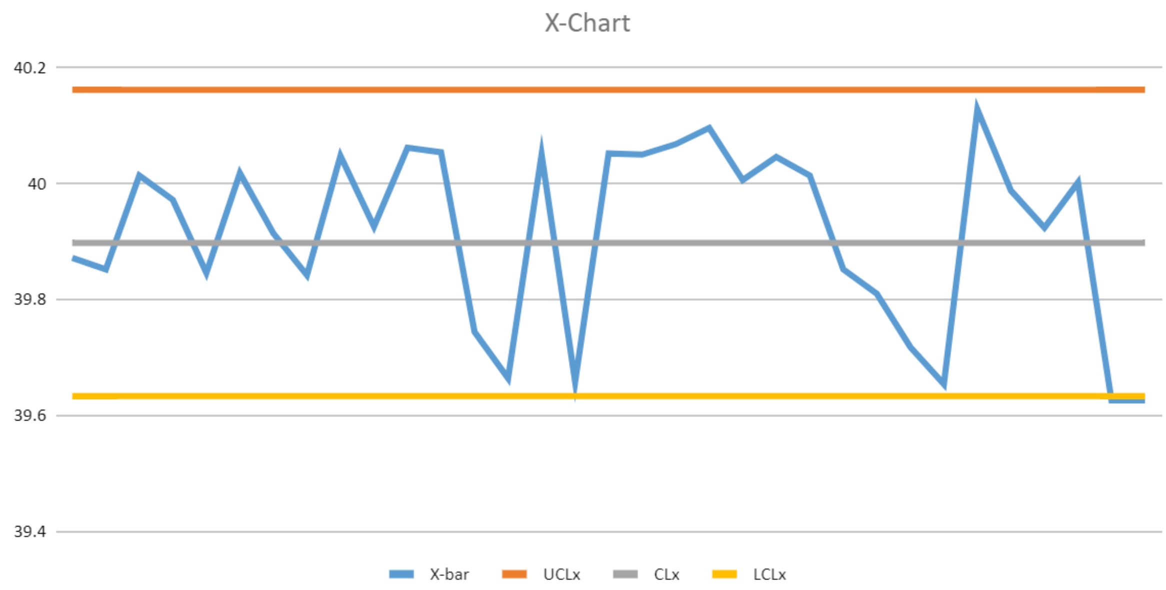


Figure (18) Adjusted X-bar Chart that shows consistency in paint quality

Following up on the last section, another survey aims to find out to what extent the products of the factory match the expectations set by both universal standards and customer expectations of quality. The survey was designed in an indirect way that measures these metrics/criteria according to distributors and direct customers of the paint factory. The resulting charts of some of the questions asked in the survey were as follows:

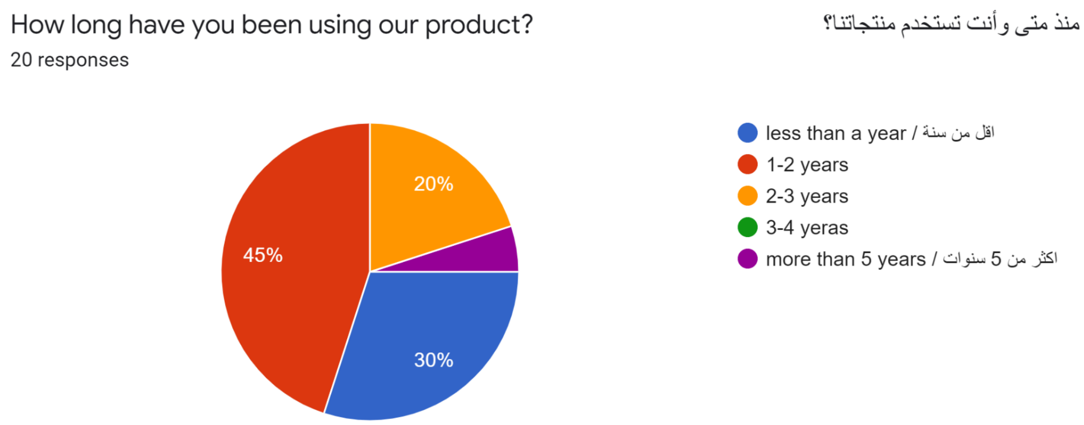


Figure (19) Pie-Chart of how long the customer has been using the factory products

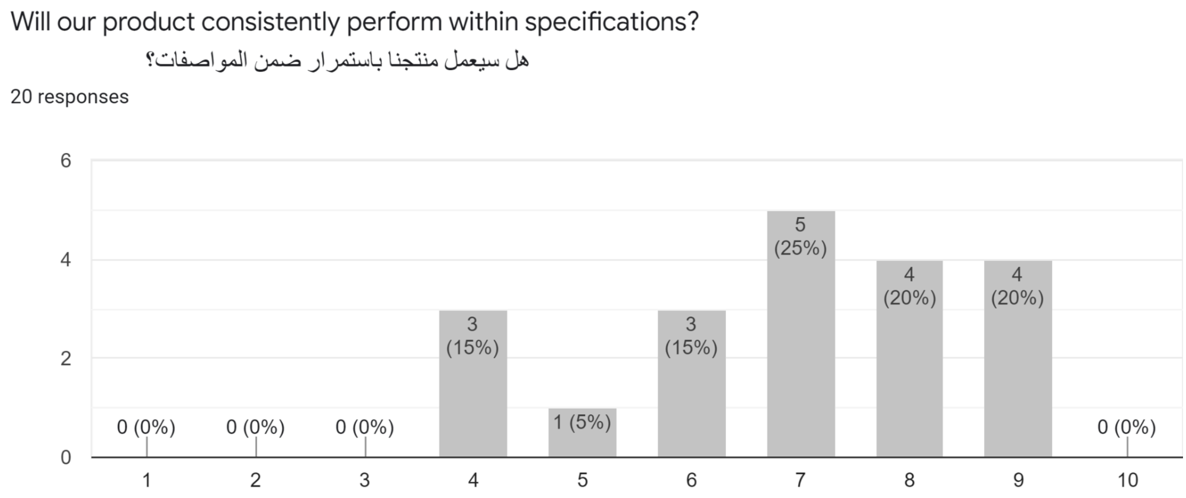


Figure (20) Histogram of product performance consistency

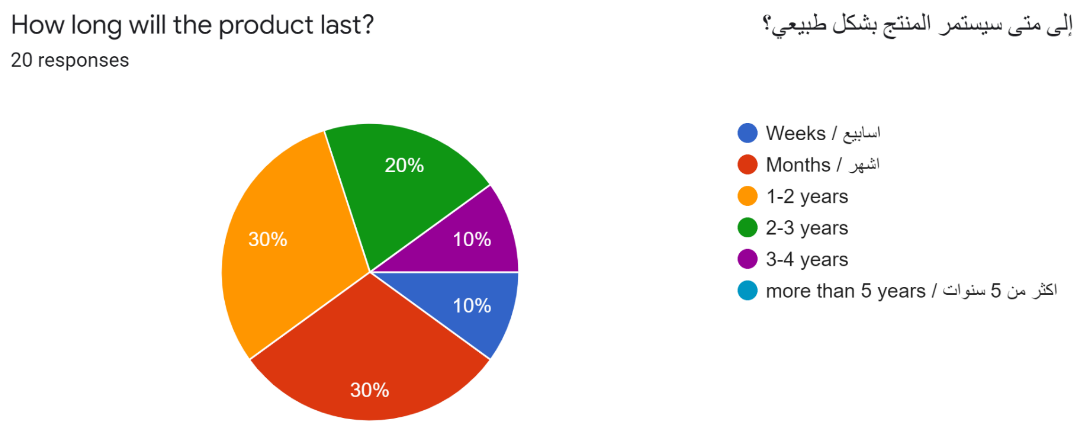


Figure (21) Pie-Chart that represents the reliability of the product

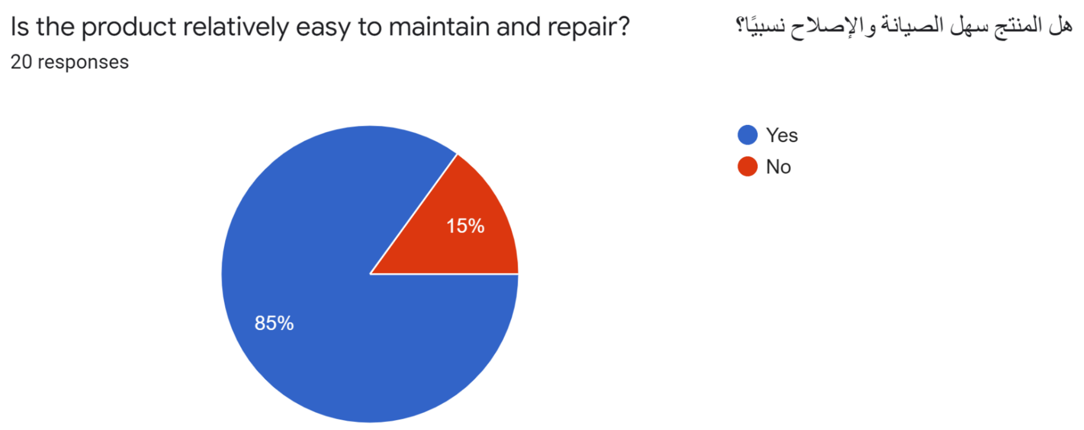


Figure (22) Pie-Chart that represents maintainability of the product

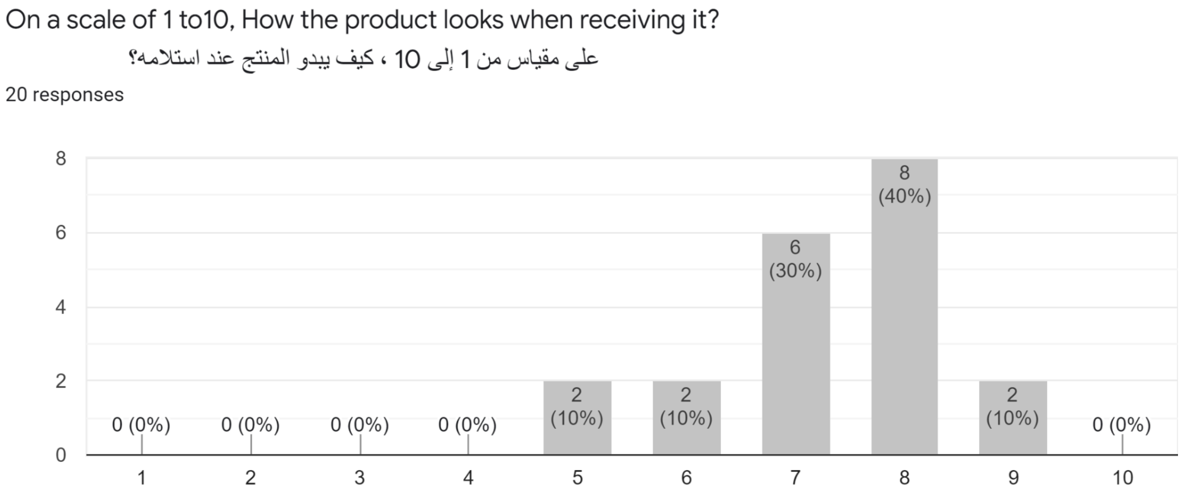


Figure (23) Histogram that shows customer satisfaction over aesthetics of the product

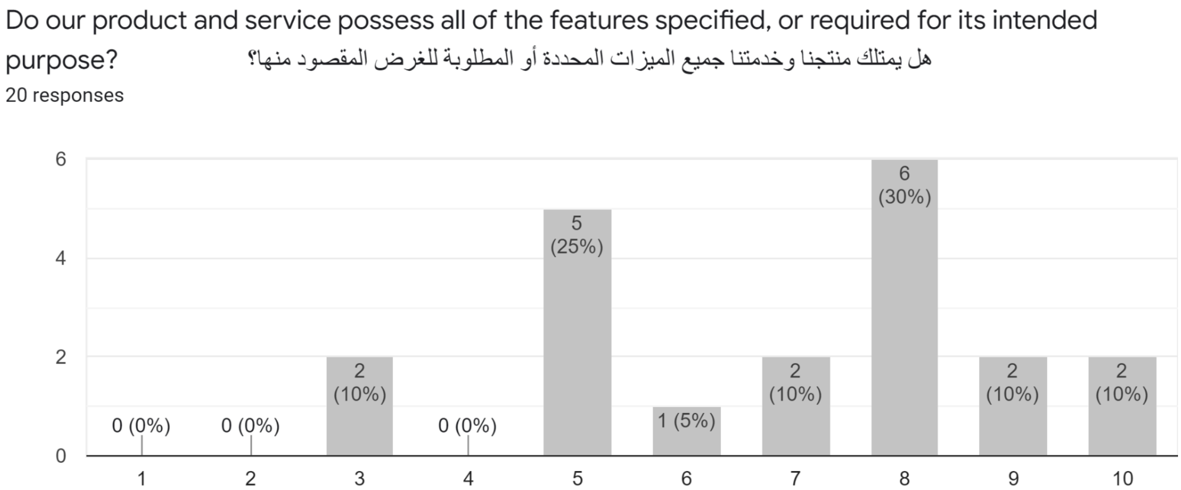


Figure (24) Histogram that shows product level of compliance to standards

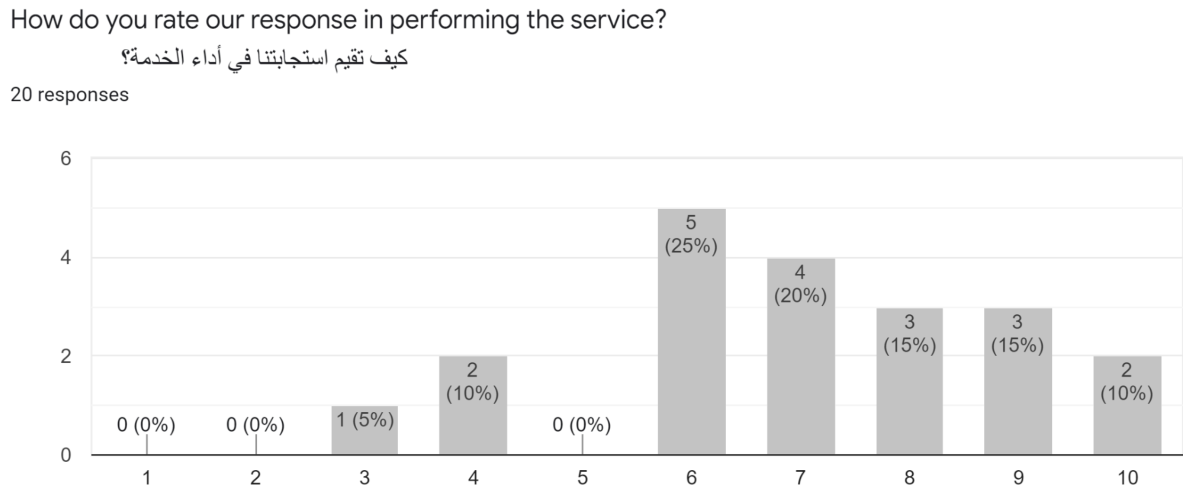


Figure (25) Histogram that shows customer rating of serviceability

After translating the data gathered from distributors and direct customers of the factory using the survey, this data was then translated using AHP tools in order to put it into the scale form used for customer requirements and expectations. This step is very sensitive and critical for the outcomes of this search in the quality control field as it will be the base to work on in the analysis phase, which will mainly hold a comparison between the two values for each criterion/metric of measurement.

Performance:

1	2	3	4	5	6	7	8	9	10

Reliability:

1	2	3	4	5	6	7	8	9	10

Durability:

1	2	3	4	5	6	7	8	9	10

Serviceability:

1	2	3	4	5	6	7	8	9	10

Aesthetics:

1	2	3	4	5	6	7	8	9	10

Features:

1	2	3	4	5	6	7	8	9	10

Perceived Quality:

1	2	3	4	5	6	7	8	9	10

Conformance to Standards:

1	2	3	4	5	6	7	8	9	10

With the values over scale for each criteria being set for all metrics/criterias of quality evaluation and the control charts being developed in a way that assures the elimination of any outliers and errors that might occur, the next phase will be a comparison that aims to understand and seeks to close the variance between the customer expectations and the actual quality of the product.

3.4 Analysis and Improvements

For this quality control improvement phase, a comparative analysis was applied in order to find differences between the quality provided by the paint company and the expected quality from customers. The eight dimensions of quality measurement were the baseline of evaluation and thus comparison.

3.4.1 Comparison Outcomes

In order to determine the quality dimensions that require improvement, the score over the scale of each dimension that the company provides had to be compared, in each dimension, to the score customers require and expect for the products. The following is a table that shows the difference between the current and expected value for each dimension and the difference in case of failure to meet the expected score:

Dimension	Current Value (C)	Expected Value (E)	Difference (E-C)
Performance	6	7	1
Reliability	5	7	2
Durability	6	8	2
Serviceability	9	8	-
Aesthetics	6	7	1
Features	8	8	-
Perceived Quality	6	7	1
Conformance to Standards	6	7	1

Table (9) Variance of provided quality from customer expected quality dimensions.

According to Table (9), the factory fulfills customers' expected quality in only two out of eight dimensions of comparison, serviceability, and features. The largest difference comes at 2 points for reliability and durability dimensions and 1 point for all other dimensions.

3.4.2 Improvements and Recommendations

The final phase in the development process of quality control procedures the paint company follows is to build solutions that will help the company provide quality products and services that meet those expectations from the customers. In order to achieve that, each dimension was further studied and improved separately. The recommendations for improvements came as the following:

1. Performance:

   Performance quality can be achieved by training and incentivizing employees and staff to raise their productivity level and efficiency of work done. Workers with better knowledge regarding their jobs or the product being produced were found to increase the quality of work done and the workers' productivity.

   Organizing materials and parts is another step in the way to increasing the performance level of production and product quality. Lowering the waste in production time and increasing the efficiency of the flow inside the facility are the main advantages of this improvement. In addition, this improvement will help avoid shortages in materials and parts. A barcode labeling system in which each and every material container and part is labeled before being organized in specified sections inside the inventory has been developed and applied for trial inside the empty containers inventory resulting in a lowered average lead time by 4 seconds, thus lowering the time waste for the paint production process.

2. Reliability:

   In order to increase the level of reliability, any faults or errors have to be prevented. One way that was suggested was by using high-quality lubricants and conducting consistent cleaning and maintenance for the production line machines. These preventive failure procedures will help avoid the wearing of machines and result in higher production efficiency and less maintenance required.

   Implementation of automation solutions and concepts will also result in decreasing the margin of error by eliminating the human factor wherever it may be found to be affecting the production process. For example, the process of filling ready containers is carried out by workers, and the weight of containers is subjected to a wide margin of error due to the human factor included in the process. A container filling machine can achieve a margin of error that is as low as 0.005, a margin that can't be achieved when a manual filling process is being carried out.

3. Durability:

   Improvement of durability for paint products by the factory can be increased by making the products more environmentally friendly. According to the survey handed to customers, 20.8% of the customers prefer environmentally friendly products.

   This improvement can be achieved by reducing the amount of volatile organic compounds used in the production process of paints inside the factory, such as methylene chloride, benzene, and formaldehyde. This solution was suggested and discussed with the company's mixing lab and is under research and development by the engineers in charge.

4. Aesthetics:

   The only aesthetic that required improvement was the packaging standards set for the paint buckets. A plastic seal for plastic buckets that had been used in order to lower fixed costs was found to be defective for the final product once the filling process began. Water-based paint's average temperature at the filling stage averages around 46 degrees celsius, a temperature that in many cases results in deformation in the shape of the bucket's upper sealing ring. This deformation resulted in many cases of failures to close the container due to the difference between the cap and the seal ring.

   To overcome this issue and reduce the waste of material, containers, and time that results from it. A metallic ring on the top of the sealing of the bucket made from aluminum with a thickness of 1.5 mm is attached to the bucket can prevent any thermal-induced deformation from occurring any longer.

   This solution is still under development, and a sample is being studied in order to achieve the most efficient design with the lowest cost of production possible.

5. Perceived Quality:

   Most of the improvements that can be applied in order to achieve the perceived quality required are by working on branding and marketing the products of the company and working on the social media representation and marketing, not to mention the service level provided by the company. These aspects can be fulfilled by relating to marketing and branding specialists in order to achieve more efficient solutions.

6. Conformance to Standards:

   Conformance to standards is a continuous process due to the change in market standards over time. Thus, collecting and analyzing customers' feedback is the most important step in order to achieve this conformance. Internal audits inside the facility will also come in handy as they will ensure the production line increased productivity and flow efficiency.

4. Safety

4.1 Introduction

The final chapter of the development process of the paint company's factory is safety engineering and management. Safety is a very critical and sensitive issue when it comes to development processes in all fields. In order to investigate safety issues that require improvement, the safety measures and protocols followed inside the facility have to first be quantified and qualified based on the safety standards. Followed by running scenarios of injuries for each hazard present, the improvements and recommendations can then be discussed and evaluated depending on the level of danger and type of hazard in each case.

4.2 Data Collection

The first step in the data collection phase is to set the type of data required and its sources. In the paint factory case, two main sources were selected to collect data. First are the production line supervisors and managers who received a checklist that contains aims to test the existence of various safety measures. The measures listed test all safety standards that paint factories should meet on-site.

Safety Measure	**State**
Emergency Button for Machines	Active for all machines
Instructions Board for Machines	Present for all machines
Alert Systems for Machines	Active for all machines
Ventilation System	Active for production line and laboratory
Safety Signs	Wherever Necessary
Fire Extinguishers	Active all around the facility
Personal Protective Equipment	Present
Eye and Face Protection	Absent for workers
Head Protection	Absent for workers
Legs Protection	Absent for workers
Special Purpose Shoes	Present for Production Line Workers
Arm Protection	Absent for workers
Protective Gloves	Present for all Workers
Masks	Absent for workers
Emergency Exits	3

Table (10) Checklist for safety measurements filled by factory management

Another table was prepared to measure and evaluate hazards endangering workers and employees inside the facility. The Table measures the level of injury for each present hazard:

Kind of hazards	**minor**	**moderate**	**serious, not life-threatenin g**	**severe, life-threatening , survival probable**	**critical, survival uncertain**	**unsurvivable**
falling from high places				X		
Large Objects failing in employees			X			
Splashes of solvents into eyes			X			
Skin Exposure through contact with solvents			X			
Exposure to vapors		X				
Blackout for 2mins	X					
Muscle cramps	X					
Sprained shoulder/wrist		X				
Back pains	X					
Burns			X			
Slipping and falling	X					

Table (11) Level of Injury depending on hazard type

The last step in the data collection process was to measure the awareness of workers and employees of the present hazards and the safety measures that need to be taken into consideration. This was achieved through a survey that was handed to the production line workers inside the facility. 24 responses were received, and the results were as the following:

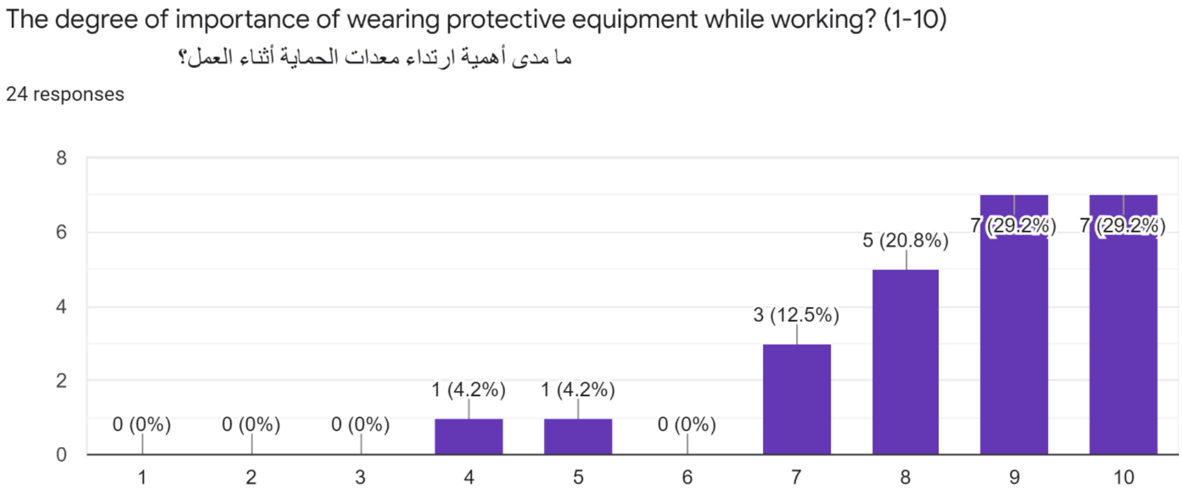


Figure (26) Histogram of workers' evaluation of protective equipment importance

Figure (27) Pie-Chart of workers' knowledge of their job hazards

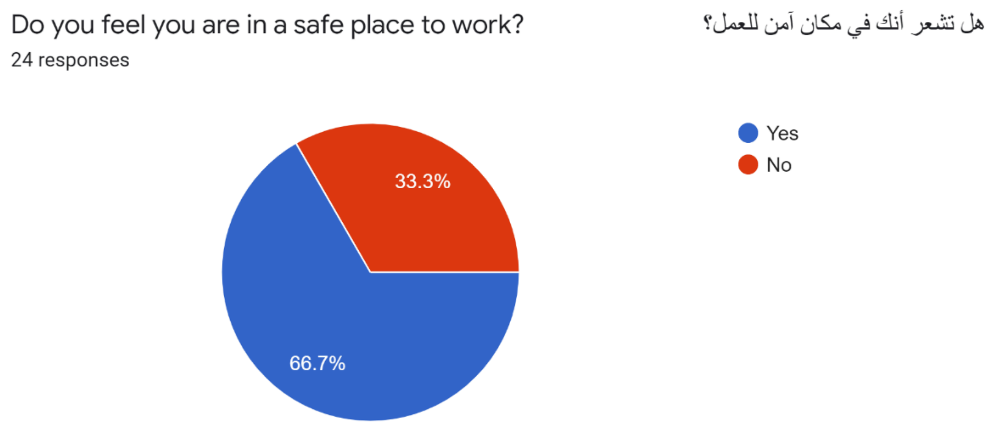


Figure (28) Pie-Chart shows the percentage of workers that feel safe in the workplace

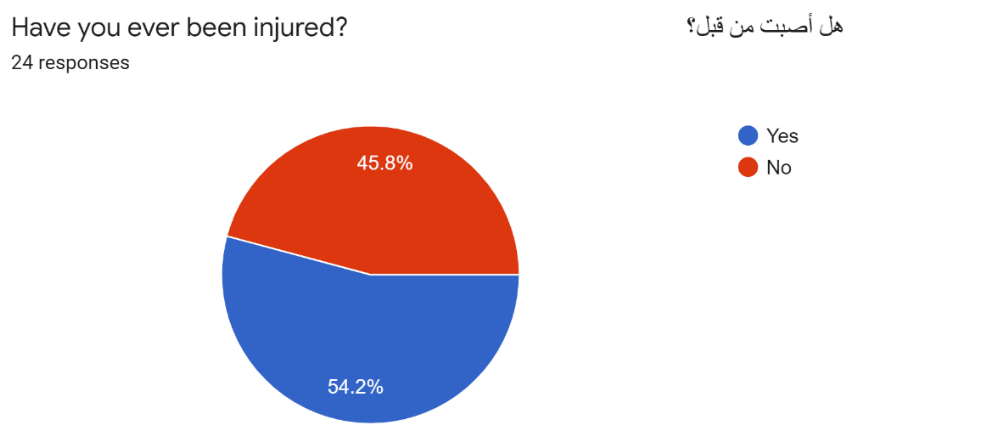


Figure (29) Pie-Chart shows the percentage of workers with a history of injuries at work

With the workers' awareness of existing hazards and dangers that their jobs inside the facility include. The data collected is now ready to be discussed and further studied in order to recommend any improvements that would ensure a safe workplace for paint factory employees and workers.

4.3 Analysis and Improvements

Safety measures are very critical and sensitive and thus have to be studied thoroughly and in detail. Multiple safety equipment and tools listed in the checklist ceased to exist, although they might be very critical. These equipment and tools are:

1. Eye and Face Protection (To avoid the hazard of splashes of solvents in contact with the eye)
2. Legs Protection. (To avoid the hazard of falling heavy objects)
3. Arm Protection. (To avoid burns through contact of chemicals with skin)
4. Masks. (To avoid the hazard of exposure to vapors)
5. Head Protection. (To avoid the hazard of falling heavy objects)

All of these missing equipment and tools were reported to the facility management and were all provided for all workers within 14 days.

The fire system inside the facility contains:

1. Many Powder fire extinguishers in all departments and outdoor (6kg, 12kg, and 50kg)
2. 3 CO_2 extinguishers in the lab (2kg)
3. 6 Fire hoses:
   - 2 in finished goods store
   - One management department
   - One in the laboratory
   - One in empty buckets store
   - One in raw materials store

In conclusion, despite the facility taking safety measures and hazards seriously, multiple hazards are present, and a few safety measures were not taken into consideration. These measures and hazards were all reported and fixed by the engineers in charge.

5. Methodology & Conclusions

5.1 Methodology

Throughout this case-study the methodology followed relied on the scientific approach of cause and effect. By studying the data collected in each sector and finding the relations between all metrics and the factors that control their values as a first phase, a wider vision of the issues present was achieved. Followed by the analysis phase which was accomplished by referring to statistical and analytical theories in order to ensure accuracy and precision of the outcomes of this phase. The process then reaches an end with the improvement and recommendations phase which yields the outcome of studying alternatives and solutions for the issues concluded in the analysis phase.

5.2 Conclusions and Summary

In general, most of the improvements in each chapter were in the form of recommendations that were handed over to the factory management. Other improvements were applied by the factory management, these improvements were in both the supply chain and safety sectors.

On the one hand, all the improvements that came as an outcome of the analysis performed in each chapter of this report were in the form of recommendations that were handed out to Fixtone Paints. Every recommendation was discussed and its specifics justified by the analysis with the factory management in order to study its applicability. The managing department was open for improvements and showed intention to work on most of the recommendations they received. The recommendations that were applied and their effect measured included:

1. Installation of an interior HVAC that is located near the mixers in the production line in order to lower the thermal factor effect over the paint quality, thus lower the quality losses.
2. A barcode labeling system in which each and every material container and part is labeled before being organized in specified sections inside the inventory.
3. A metallic ring on the top of the sealing of the bucket made from aluminum with a thickness of 1.5 mm is attached to the bucket in order to prevent any thermal-induced deformation.
4. Adjusting several safety measures that have to do with the workers in the production line.

On the other hand, a few recommendations are either under further studying by the company's engineers or awaiting approval by the management. For all these recommendations, a plan of application is being developed following up to this process. These recommendations included:

1. Adjusting the Days Payable Outstanding by quarterly determining the cost of goods sold for the quarter and multiplying by 90 days instead of 365.
2. Reducing the amount of volatile organic compounds used in the production process of paints inside the factory in order to increase durability.
3. Internal audits inside the facility that can increase the level of conformance to standards.
4. Using high-quality lubricants and conducting consistent cleaning and maintenance for the production line machines.

To sum it all up,

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Appendix A. **Table of Control Chart Constants**

Table of Control Chart Constants

X-bar Chart for sigma R Chart Constants S Chart Constants Constants estimate

Sample Size = m	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.628	2.059	0	2.282	0	2.266
5	0.577	1.427	2.326	0	2.114	0	2.089
6	0.483	1.287	2.534	0	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0.266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.850	3.336	0.307	1.693	0.382	1.618
14	0.235	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.653	0.428	1.572
16	0.212	0.763	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.534
18	0.194	0.718	3.640	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.180	0.680	3.735	0.415	1.585	0.510	1.490
21	0.173	0.663	3.778	0.425	1.575	0.523	1.477
22	0.167	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

Control chart constants for X-bar, R, S, Individuals (called "X" or "I" charts), and MR (Moving Range) Charts. NOTES: To construct the "X" and "MR" charts (these are companions) we compute the Moving Ranges as:

R_2 = range of 1st and 2nd observations, R_3 = range of 2nd and 3rd observations, R_4 = range of 3rd and 4th observations, etc. with the "average" moving range or "MR-bar" being the average of these ranges with the "sample size" for each of these ranges being n = 2 since each is based on consecutive observations ... this should provide an estimated standard deviation (needed for the "I" chart)