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DEFECT REDUCTION IN VINTAGE CAR REPAINTING

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วิทยานิพนธ์ฉบับนี้มีจุดประสงค์เพื่อลดของเสียชนิด blistering/solvent boil และ dust contamination ในกระบวนการทำสีรถโบราณ

จากการศึกษาข้อมูลพบว่า ผลิตภัณฑ์ที่มีปริมาณของเสียในอัตรา 100% ซึ่งสาเหตุหลักมาจากความสกปรกของอุปกรณ์ที่ใช้ในกระบวนการพ่นสี และ การเลือกใช้อุปกรณ์ไม่เหมาะสม ส่งผลให้บริษัทต้องศูนย์เสียเวลาและต้นทุนในการแก้ไขเป็นจำนวนมาก ดังนั้นจึงจำเป็นต้องปรับปรุงกระบวนการผลิตอย่างเร่งด่วน ซึ่งทีมงานได้ทำใน 5 ขั้นตอนคือ การนิยามปัญหา การวัดเพื่อกำหนดสาเหตุของปัญหา การวิเคราะห์สาเหตุของปัญหา การปรับปรุงแก้ไขกระบวนการ และ การควบคุมกระบวนการ ตามลำดับ การดำเนินงานในการปรับปรุงคุณภาพนั้น เริ่มจากการศึกษากระบวนการทำงานเพื่อหาปัจจัยที่ส่งผลกระทบต่อการเปิดปัญหา blistering/solvent boil และ dust contamination โดยทำไปพร้อมกับการศึกษาความแม่นยำและถูกต้องของระบบการวัด การวิเคราะห์สาเหตุของปัญหาด้วยแผนภาพแสดงเหตุและผลและคัดเลือกตัวแปรที่จะนำมาศึกษาโดยการใช้เทคนิคลักษณะบกพร่องและผลกระทบ(FMEA) จากนั้นจึงนำเอาปัจจัยที่คาดว่าจะมีผลต่อปัญหามาทำการทดสอบด้วยวิธีทางสถิติ และหาพารามิเตอร์ที่เหมาะสมของกระบวนการ โดยการประยุกต์การออกแบบการทดลอง และควบคุมกระบวนการผลิตเพื่อป้องกันปัญหาไม่ให้เกิดขึ้นซ้ำอีก

จากการปรับปรุงกระบวนการพ่นสี พบว่าจำนวนของเสียที่เกิดขึ้นจากกระบวนการหลักการปรับปรุงสามารถลดของเสียชนิด blistering/solvent boil ได้ 81.5% และสามารถลดของเสียชนิด dust contamination ได้ 59.02%

ภาควิชา.ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต.. ลายมือชื่อนิสิต......................................
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CHAKRAPHOL CHULAJATA: DEFECT REDUCTION IN VINTAGE CAR REPAINTING. ADVISOR: ASSOC.PROF.PARAMES CHUTIMA, Ph.D., 129 pp.

The objective of this research is to reduce blistering/solvent boil defective and dust contamination defective in vintage car repainting

From the research, the both defect rates are 100% that the major causes of the defects result from dirty equipment and wrong using of equipment and material that cause waste in rework cost in terms of both time and expense including re-inspection cost. These 5 steps are exercised in this research including defining phase, measurement phase, analysis phase, improvement phase and control phase respectively. This research studied in details of the production process to find factors that cause both defects in the measurement and analysis phases. The main factors were selected and analysed by Failure Mode and Effect Analysis (FMEA) Then, those factors were tested by statistic and found the suitable parameter settings of the process by Design of Experiment (DOE). Having found the appropriate parameters, the process was controlled to protect reoccurrence problems.

After the improvement of painting processes, it is found that the blistering/solvent boil defect is reduced 81.5% and dust contamination is reduced 59.02% of the defect before the improvement.

Department : ….Regional Center for Manufacturing… Student's Signature……………..
…………..Systems Engineering…..…… Advisor's Signature……………..
Field of Study : ………Engineering Management…….
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CHAPTER I

INTRODUCTION

Today, the business world become more competitive and the less competitive businesses are eliminated. Companies have tried to gain competitive advantage in as many as possible aspects. In order to be survival in the vintage cars restoration business, the companies have to provide the highest quality work with reasonable price. Because they usually work with rare car, reputation and reliability has also taken one of the major roles. The case study company competitiveness is reputation in the vintage car restoration business while the painting quality is considered average comparing in the car painting business and a bit below average comparing to other vintage car company.

1.1 Company Background

The case study company was established in 2004. The company is a specialist in vintage car restoration from "Part Car" rating to "Excellent" Rating. The company operation can be categorized to two sectors, repairing department and painting department.

CLASSIC CAR
CONDITION RATING GUIDE

RATING	DESCRIPTION
1	EXCELLENT/SHOW CAR *A masterpiece, this perfect original car is in the same condition it was in when delivered new or better; or a professionally-restored car that has been restored to new or better than new condition. This car is not driven, and is transported to shows in an enclosed trailer. Normally stored in a secured, temperature and humidity controlled environment when not being shown, this car would be expected to come within a point or two of a perfect score when judged by professionals using current criteria.*
2	FINE *An original car with very low miles that has been meticulously maintained since new; or an older professional restoration that has seen very limited use since restoration. Very close inspection by an expert may detect almost insignificant flaws or wear, but to most enthusiasts the car would look perfect. This car would come within several points of a perfect score when judged, and would receive the top award at a show unless a true Number 1 car were also being judged.*
3	VERY GOOD *A well-maintained original car that has been driven limited miles over the years; is completely operable with all equipment working as designed, and at first glance may look perfect; or an older restoration that has been driven limited miles since the restoration was completed, and is showing minor wear and tear from being on display at car shows. Closer inspection may reveal minor wear on parts susceptible to showing wear, such as brake and gas pedals, and some thinning of paint and chrome finishes may also be noticed.*
4	GOOD *Major components function properly, and the vehicle is completely safe to drive but may need minor repairs to mechanical systems. No parts are missing, but this car has been driven on a regular basis and may need a paint job and a few trim pieces rechromed or replaced. Amateur restorations usually fall into this category, as do very old professional restorations that have deteriorated due to use and exposure to the elements.*
5	RESTORABLE *May or may not be running; everything on the car needs to be restored; may be missing minor parts, but the major components are there. Any body damage due to collision or rust should be minor; some surface rust may appear, but no holes should be present. The car is structurally sound, but needs cosmetic updating to paint, upholstery and top material, as well as repairs to various mechanical components.*
6	PARTS CAR *Probably not running well, if at all; missing some major as well as minor parts; may have serious body damage due to wreck or rust through. Soft trim and rubber parts are most likely completely ruined from weathering and exposure. This vehicle needs many parts and has deteriorated to the point of not being a good candidate for restoration.*

Other sources list vehicle condition on a 1-4 or 1-5 scale; we believe the 1-6 scale above allows a better representation of overall vehicle condition, and leaves less to individual interpretation. There doesn't seem to be one specific industry standard at this time.

Figure 1.1.Classic Car Condition Rating Guide (Automotive Mileposts, 2000)

1.2 Painting Processes

The following are the description for car painting processes.

- Preparing phase

Car has to be coated with primer in order to bond the metal and other coat. Then body filler is filled in the hole or create the shape of car body as it should be. Then the preparing surface is sanded to smooth the surface.

- Painting Phase

First, car is cleaned and grease is removed be grease remover. At this stage, some area of the car surface is covered with primer and some area is body filler. Sealer is painted on top of it to lock everything under it and act as a uniform surface to put the actual color on it. Then, the topcoat that is the real car color is painted for the last ones. Usually the minimum of the topcoat layers are three. Flash off time between each layer is 10 minute. After left at least 8 hours, the surfaces is sanded and buffed to make a car shining. The rest of the defects are eliminated in this step.

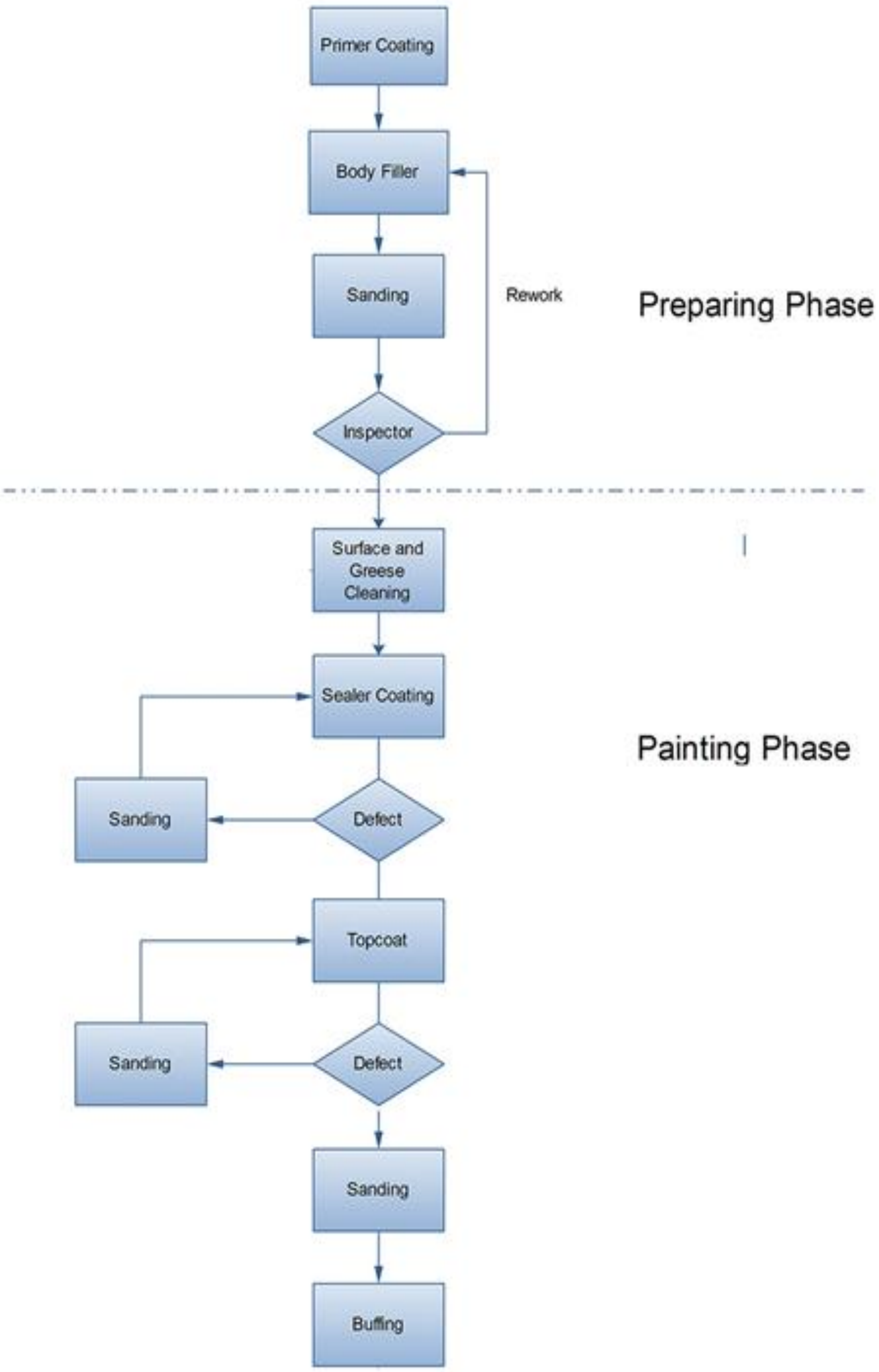


Figure 1.2. Painting Processes

1.3 Statement of Problem

The collected data since September 2009 shows that the defect rate of the spray painting is 100%. Some defect has not happen regularly, but some defect has happen on every painted car. The examples of defect that occur are categorized below.

- Contamination in Processes
  - Solvent Boil: Blister-like surface defects due to solvent entrapment in the surface of the paint film.

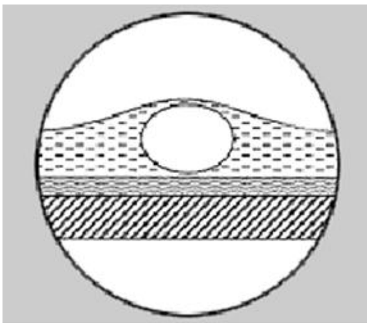


Figure 1.3. Solvent Boil (Glasurit, 2010)

  - Blistering: a small quantity of water vapour is absorbed into the paint structure and is then evaporated again in dry conditions (osmosis)

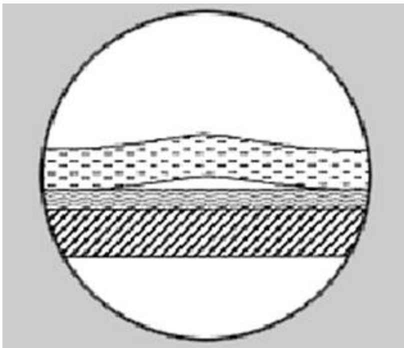


Figure 1.4. Blistering (Glasurit, 2010)

  - Dust Contamination: Usually small, irregular particles in the paint film caused by foreign matter (e.g. dust/dirt) which can occur in different sizes, shapes, types and patterns.

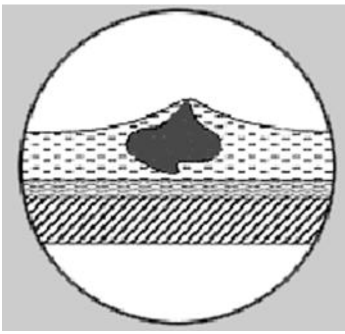


Figure 1.5. Dust Contamination (Glasurit, 2010)

- Fault in Processes
    - Orange-Peel: Poor surface texture of the paint similar to the surface texture of an orange skin.

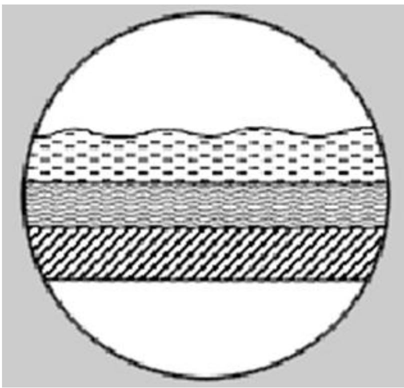


Figure 1.6. Orange-Peel (Glasurit, 2010)

    - Run/Sags: These are beads, droplets, larger globules or "curtain effect" in the paint finish on vertical surfaces.

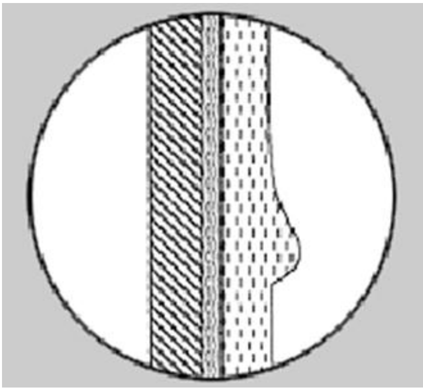


Figure 1.7. Run/Sag (Glasurit, 2010)

- Overspray: Fine dry atomized spray droplets from the painting process stuck to the surface, or droplets that have not been absorbed by the paint film.

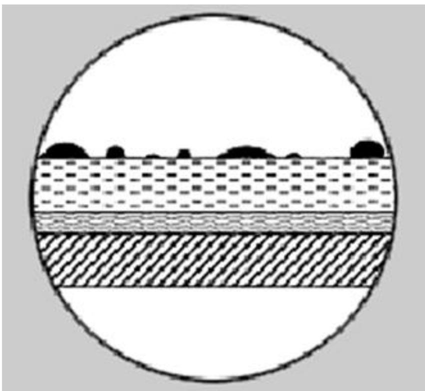


Figure 1.8. Overspray (Glasurit, 2010)

- Cratering (Fish-eyes): Circular recesses with a diameter from 0.5 to 3 mm. The problem may range in appearance from a very flat recess in the top-coat to a deep fault which extends back to the substrate.

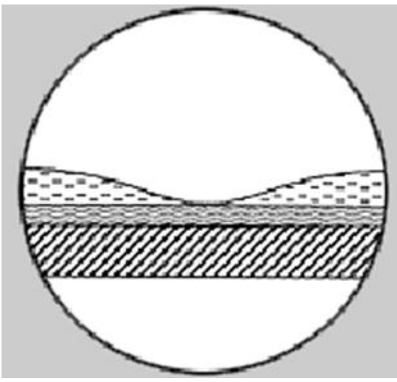


Figure 1.9. Cratering (Glasurit, 2010)

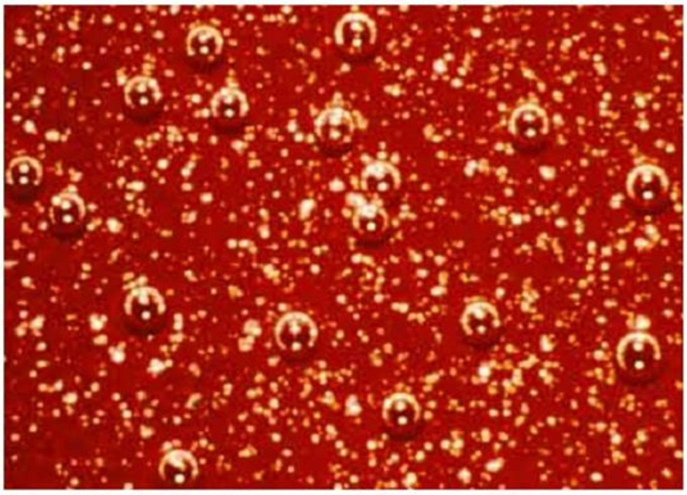
The defects are able to be categorized by their occurrence as well.

Type 1. The defects that occur in the process are :	• Solvent Boil • Blistering • Dust Contamination • Orange-Peel • Run/Sags • Overspray • Cratering
Type 2. The defects that occur a week to several months after the painting are finished are :	• Solvent Boil • Blistering
Type 3 The defects that affect to overall quality, but they can't measure by eyes are :	• Solvent Boil • Blistering

The following table shows the inspection defects in the 32 painted cars.

Defect	Defective(per car)	Defective (% per car)
Solvent Boil / Blistering	32	100%
Dust Contamination	32	100%
Overspray	20	62%
Cratering	14	43%
Run/Sags	3	9%
Orange-Peel	1	3%

Type one defects are able to be visually detected and eliminated in the rework and sanding process, however, the rework consumes cost and time. Type two defects do not show up promptly. Their occurrence is depended on the quality of the painting that affect to the reputation of the company. Type three defects are not visible in term of quantitative, but they affect to the overall quality of the paint job.



Solvent-Boil in Clear Lacquer coat, 100 x magnification

Figure 1.10. Solvent Boil at 100x magnification (Glasurit, 2010)

1.4 Objective of Thesis

The objective of the thesis is to reduce defects in painting process.

1.5 Scope of Thesis

The thesis on Defect Reduction in Vintage Car Repainting will be researched and written under the following scope:

1. The study is focused on the topcoat painting process on prepared surface and there is no any defect left from previous processes.
2. The study is conducted base on full-body painting process for vintage car with Glasurit 22 Line material.
3. Quality cost is focused on the actual cost concurred in machine, material and direct labour cost only, administrative is excluded.

1.6 Expected Benefits

The direct benefit of defect reduction program is to create high quality painting processes. There are some of the benefits of the thesis in both direct and indirect way.

1. Increase the life time of painted work.
2. Reduce cost by decreasing defects.
3. Increase customer satisfaction.
4. Increase reputation of the company.

1.7 Research Methodology

1. Review the literatures and related study.
2. Gather statistic data and relevant information of existing problem in the painting process.
3. Analyse the accuracy of measuring method.
4. Identify possible causes and effect of defect in the painting process.
5. Brainstorm and analyse possible causes and effects of the problem and discuss the estimating of severity, occurrence and detection.
6. Develop and test the hypotheses on significant cause and effect relationship.
7. Analyse the dependent of the results by using several tools.
8. Identify the experiment procedure and result gathering.

9. Design control plans and document of improved processes and setup standard operating procedures.
10. Summarize the result of study
11. Write up and submit thesis.

CHAPTER II

LITERATURE REVIEW

This chapter includes the description of the theories and recent applications related to the problem in this research. There are 4 main topics to be discussed; those are applications concerning the quality control tools such as GR&R, C&E Diagram and Matrix, FMEA and DOE, car repainting system and compressed air system and environment.

In this research, the quality control tools are initiated with the objective to reduce painting defect. Car repainting system and compressed air system and painting environment are highly focused in this research to solve the problem studied in this thesis.

2.1 Quality Control Tools

2.1.1 Gage R&R

When operator does not measure a part consistently, the expense to a company can be very great: satisfactory parts are rejected and unsatisfactory ones are accepted. The tool to address the operator consistency is gage repeatability and reproducibility (R&R), which is the evaluation of measuring instruments to determine capability to yield a precise response.

In a gage R&R, the following characteristics are essential. (Breyfogle, 2003)

- The measurement must be in statistical control, which is referred to as statistical stability. This means that variation from the measurement system is from common causes only and not special cases.
- Variability of the measurement system must be small compared with both the manufacturing process and specification limits.
- Increments of measurement must be small relative to both process variability and specification limits. A common rule of thumb is that the increments should be no greater than one-tenth of the smaller of either the process variability or specification limits.

Gage repeatability is the variation in measurements considering one part and one operator. Gage reproducibility is the variation between operators measuring one part.

2.1.2 Cause & Effect Diagram

Cause-and-effect diagram (Breyfogle, 2003), known as Ishikawa diagram, is useful to trigger ideas and promote a balanced approach in group brainstorming sessions in which individuals list the perceived sources (causes) of a problem (effect). A cause-and-effect diagram provides a means for teams to focus on the creation of a list of process input variables that could affect key process output variables. The technique can be used to determine the factors to consider within a regression analysis or DOE.

When constructing a cause-and-effect diagram, it is often appropriate to consider six area or causes that can contribute to a characteristic response or effect, materials, machine, method, personnel, measurement, and environment. Each one of these characteristics is then investigated for sub causes that are specific items or difficulties that are identified as a factual or potential cause to the effect.

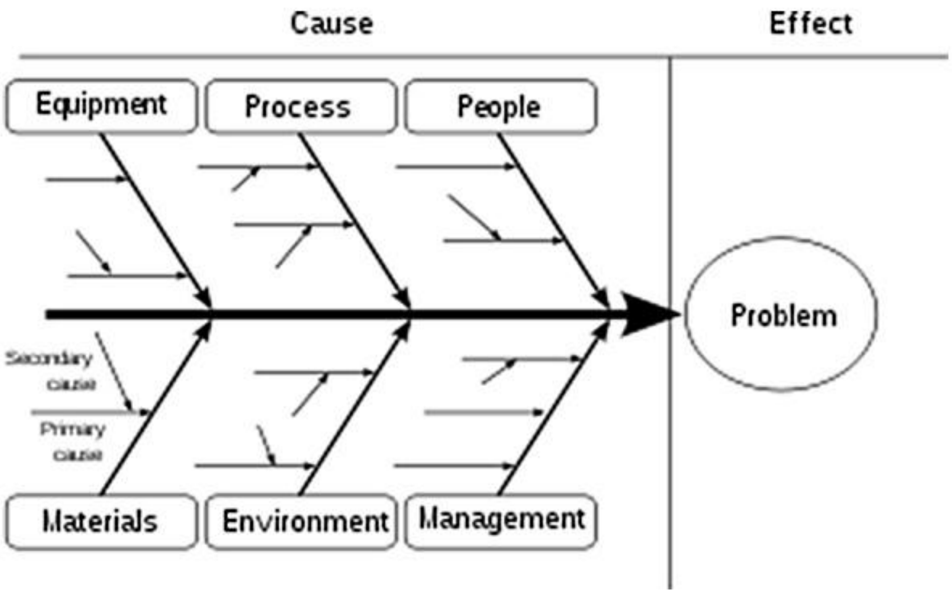


Figure 2.1 Cause & Effect Diagram (Paulsen, 2010)

2.1.3 Cause & Effect Matrix

The C&E matrix is a tool that can aid with the prioritization of importance of process input variables. This relational matrix prioritization by a team can help with the selection of what will be monitored to determine if there is a cause and effect relationship and whether key process input controls are necessary. The results of a C&E matrix can lead to other activities such as FMEA and DOE.

The processes to construct a C&E matrix are described below.

1. List horizontally the key process output variable that were identified when documenting the process. These variables are to represent what the customer of the process considers important and essential.

2. Assign a prioritization number for each key process output variable, where higher numbers have a larger priority such as using values from 1 to 10. These values do not need to be sequential.

3. List vertically on the left side of the C&E matrix all key process input variables that may cause variability or non-conformance to one or more of the key process output variables.

4. Reach by consensus the amount of effect each key process input variable has on each key process output variable. Rather than use values from 1 to 10 (where 10 indicates the largest effect), consider a scale using levels 0, 1, 3, and 5 or 0, 1, 3, and 9.

5. Determine the result for each process input variable by first multiplying the key process output priority (step 2) by the consensus of the effect for the key process input variable (step 4) and then summing these products.

6. The key process input variables can then be prioritized by the results from stem 5 and/or a percentage of total calculation.

2.1.4 Failure Mode and Effect Analysis (FMEA)

FMEA was first published in US Armed Forces Military document in 1949. Then, in 1960s, FMEA was developed by the aerospace/rocket development to avoid errors in costly rocket technology. In the late 1970s Ford Motor Company introduced FMEA to the automotive industry to consider potential process induced failures prior to launching production.

1. FMEA Definition

A failure mode and effect analysis (FMEA) (Stamatis, 1995) is a technique used to define, identify, and eliminate known and/or potential failures, problems, errors and so on from the system, design, process, and/or service before they reach the customer.

The essence of the FMEA is to identify and prevent known and potential problems from reaching the customer. To do that, the assumptions of the problems that have different priorities have to be made. There are three components that help to define the priority of failures.

- Occurrence (O)
- Severity (S)
- Detection (D)

Occurrence is the frequency of the failure. Severity is the seriousness of the failure. Detection is the ability to detect the failure before it reaches the customer. To define these values, numerical scales (called risk criteria guidelines) have to be assigned to each component. These guidelines can be qualitative and/or quantitative.

Theoretical behaviour of the component must be followed, if the guideline is qualitative. For example, in the case of the occurrence the expected behaviour is normality. This behaviour is expected because frequencies over time behave in a normal fashion. Thus the guideline should follow the normal distribution. In the case of severity, the expected behaviour is lognormal. This behaviour is expected because the failures that occurred should be of the nuisance category as opposed to critical or catastrophic. Thus, the guideline should follow a distribution that skews to the right (positively skewed). In the case of the detection, the expected behaviour is that of a discrete distribution. This is expected because there is more concern if the failure is found by the customer as opposed to finding the failure within the organization. Therefore, there is a discrete outcome (internal organization versus customer) in the detection. Thus, the guideline should follow a distribution with a gap between the values. If the guideline is quantitative, it must be specific. It must follow actual data, statistical process control data, historical data or surrogate data for the evaluation. The racking for the criteria can have any value. There is no standard for such value; however, there are two very common rankings used in all industries today, 1 to 5 scale or 1 to 10 scale. The ranking of 1 to 10 is used widely and, in fact is highly recommended because it provides ease of interpretation, accuracy and precision in the quantification of the ranking. Rankings of higher than 1 to 10 scales are not recommended because they are difficult to interpret and lose their effectiveness. The priority of the problems is articulated via the RPN. This number is a product of the occurrence, severity and detection. The value by itself should be used only to rank order and concerns of the system, design, product, process and service. All RPNs have no other value or meaning

At that point the order is determined by the magnitude of the RPN for each of the failures. (The high RPN failures are addressed first, then the lower, and so on until all failures have been resolved.) To undertake an analysis of all problems at the same time is not recommended and is contrary to the philosophy of the FMEA. The threshold of pursuing failures/problems is an RPN equal to specific number that can be changed for any given statistical confidence or scale. For example, if the statistical confidence is 90 percent with a scale of 1 to 10, then the threshold becomes 100.

After the RPN has been determined, the evaluation begins based on the definition of the risk. Usually this risk is defined by the team as minor, moderate, high and critical. It may be changed to reflect different situations.

- Under minor risk, no action is taken
- Under moderate risk, some action may take place
- Under high risk, definite action will take place. (Selective validation and evaluation may be required.)
- Under critical risk, definite actions will take place and extensive changes are required in the system, design, product, process or service.

If there are more than two failures with the same RPN, then first address the failure with high severity and then detection. Severity is approached first because it deals with the effects of the failure. Detection is used over the occurrence because it is customer dependent, which is more important than just the frequencies of the failure.

2. Classification of FMEA

There are four types of FMEAs (Stamatis, 1995). The four types are:

1. System FMEA – used to analyse systems and subsystems in the early concept and design stage. A system FMEA focuses on potential failure modes between the functions of the system caused by system deficiencies. It includes the interactions between system and elements of the system.

2. Design FMEA – Used to analyse products before they are released to manufacturing. A design FMEA focuses on failure modes caused by design deficiencies.

3. Process FMEA – Used to analyse manufacturing and assembly processes. A process FMEA focuses on failure modes caused by process or assembly deficiencies.

4. Service FMEA – Used to analyse services before they reach the customer. A service FMEA focuses on failure modes (tasks, errors, mistakes) caused by system or process deficiencies.

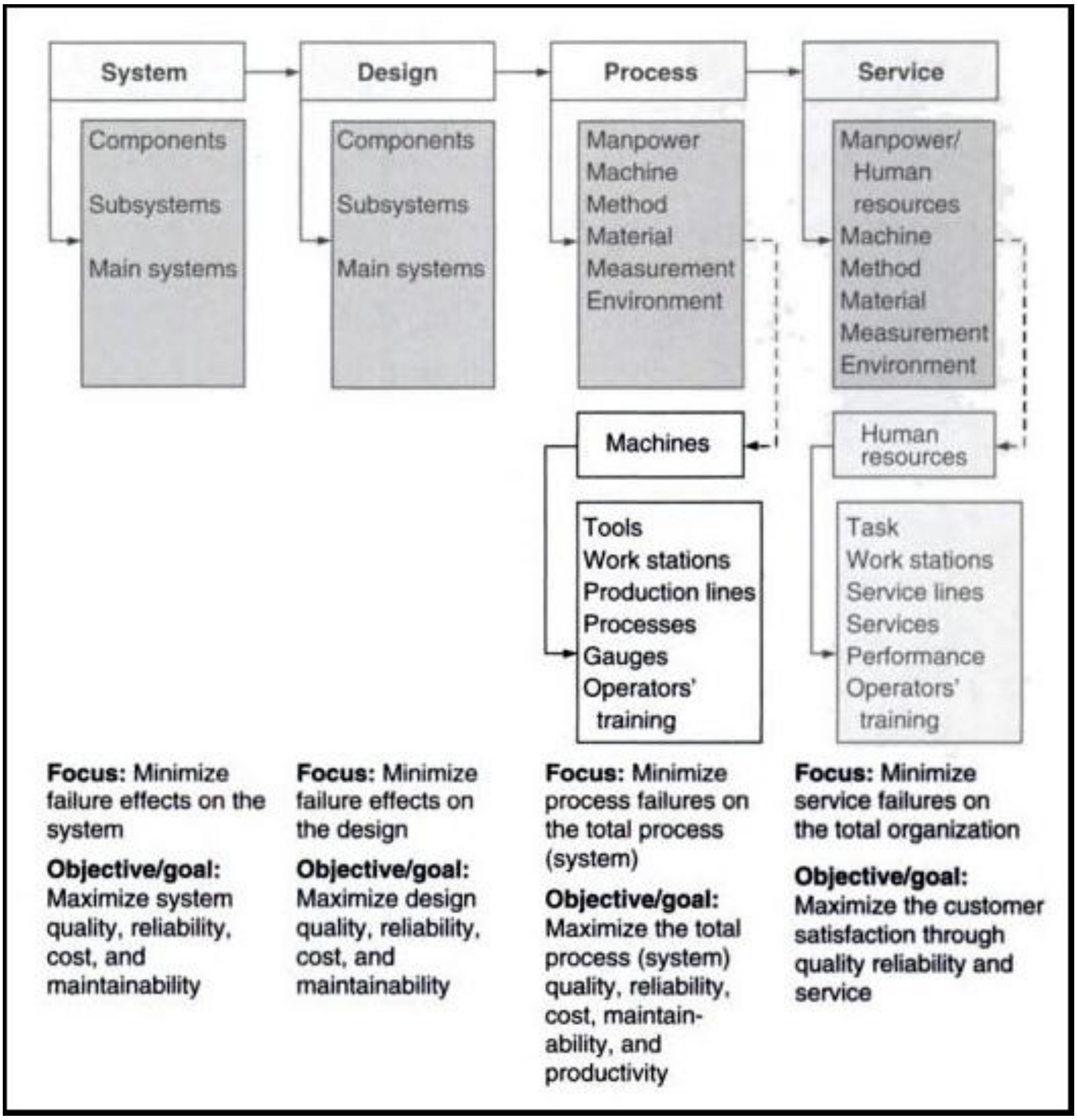


Figure 2.2 Types of FMEAs (Stamatis, 1995)

3. The Process of Conducting FMEA

To conduct FMEA effectively, the eight-step method has to be approached systematically. This method facilitates the system, design, product, process and service FMEA. (Stamatis, 1995)

1. Select the team and brainstorm – Make sure the appropriate individuals are going to participate. The team must be cross functional and multidiscipline and the team member must be willing to contribute

After the team has been identified and is in place, the team tries to prioritize the opportunities of improvement. Is the concern in a system, design, product, process or service? What kind of problems are there or what kinds are anticipated with a particular situation? Is customer or supplier involved or is continual improvement being pursued independently? If the customer or supplier has identified specific failures, then the job is much easier because direction has already been given. On the other hand, if continual improvement is being independently pursued, the brainstorm, affinity diagram, storybook method, or cause-and-effect diagram may prove to be the best tools to identify some direction.

2. Functional block diagram or process flowchart – For system and design FMEAs the functional block diagram is applicable. For the process and service FMEAs the process flowchart is applicable. The idea is to make sure that everyone understands the system and the problems associated with the system

The functional block diagram focuses the discussion on the system and design while the process flowchart focuses the discussion on the process and service. Both of these tools also provide an overview and a working model of the relationships and interaction of the systems, subsystems, components, processes, assemblies, and services and help in the understanding of the system, design, product, process or service.

3. Prioritize – After the team understands the problem, the actual analysis begins. Frequent question are what part is important and Where should the team begin. Sometimes, this step is completely bypassed because the prioritization is de facto. The customer has identified the priority or due to warranty cost or some other input the determination has been made by the management to start at a given point.

4. Data collection – This is where the team begins to collect the data of the failures and categorizes them appropriately. At this point the team begins to fill in the FMEA form. The failures identified are the failure modes of the FMEA.

5. Analysis – Now the data are utilized for a resolution. The reason for the data is to gain information that is used to gain knowledge that is contributed to the decision. This flow can be shown as follows.

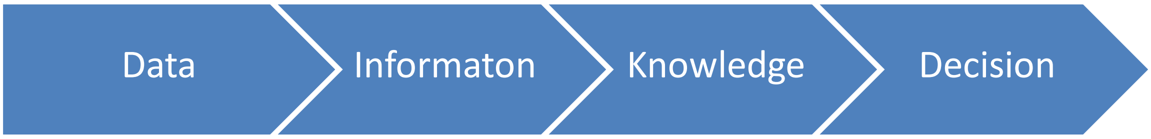


Figure 2.3 Flow of Processes (Stamatis, 1995)

The analysis may be qualitative or quantitative. The team may use brainstorming, cause and effect analysis, QFD, DOE, Statistical Process Control, another FMEA, mathematical modelling, simulation, reliability analysis and anything else that team members think is suitable.

Information from this step will be used to fill in the columns of the FMEA form in relationship to the effects of the failure, existing controls and discussing the estimation of severity, occurrence and detection.

6. Results – The theme here is data driven. Based on the analysis, results are derived. The information from this step will be used to quantify the severity, occurrence, detection and RPN. The appropriate columns of the FMEA will be completed.

7. confirm/evaluate/measure – After the results have been recorded, it is time to confirm, evaluate and measure the success or failure. This evaluation takes the form of three basic questions

- Is the situation better than before?
- Is the situation worse than before?
- Is the situation the same as before?

The information from this step will be used to recommend actions and to see the results of those actions in the corresponding columns of the FMEA form.

8. Do it all over again – Regardless of how step 7 is answered, the team must pursue improvement all over again because of the underlying philosophy of FMEA, which is continual improvement.

The long-term goal is to completely eliminate every single failure. The short-term goal is to minimize the failures if not eliminate them. Of course, the perseverance for those goals has to be taken into consideration in relationship to the needs of the organization, costs, customers and competition.

2.1.5 Design of Experiment (DOE)

Design of Experiments (Montgomery et al., 2002) is an experiment where one or more variables, called independent variables, believed to have an effect on the experimental outcome are identified and manipulated according to a predetermined plan. On the other word, it is an organized method for determining the relationship between variable factors (Xs) affecting a process and the output or response of that process (Y). In practical, an experiment is complex with many controllable and uncontrollable variables as shown.

In each variable, two or more levels are assigned called treatments. So, the experiment screen for critical variables that affect to better result of processes. Finally, the selected level of all variables will perform the best process performance. Experiment methodology involves a sequence of activities are described as following.

1. Conjecture - the setup hypothesis of the experiment
2. Experiment – the test that is performed to examine the conjecture
3. Analysis – the statistical analysis of the experiment ‘s data
4. Conclusion – the result that has been learned from the experiment about the original conjecture. Frequently, the experiment leads to a revised conjecture and a whole new experiment.

To avoid the effect of any nuisance variable that may influence the result, randomization technique may be used to balance out the experiment.

1. Single-Factor

The experiment is classified to 2 types by the number of variables, Single-Factor and Factorial experiment. Single-Factor experiment is the experiment that has a single factor of interest and there are two or more levels of the factor. The linear statistical model may be described by observations and replicates in the experiment as shown as follow.

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij} \begin{cases} i = 1,2, \dots, a \\ j = 1,2, \dots n \end{cases}$$

Where y_{ij} is a random variable denoting the (ij)th observation; μ is a parameter common to all treatments or so called overall mean; τ_i is aparameter associated with the ith treatment or so called *i*th treatment effect; and ε_{ij} is a random error component.

The hypothesis of the experiment is

$$H_1: \tau_1 = \tau_2 = \cdots = \tau_a = 0$$

$H_2: \tau_i \neq 0$ for at least one i

If the null hypothesis is true, changing the levels of the factor has no effect on the mean response.

The sums of squares computing formulas for the analysis of variance (ANOVA) with equal sample sizes in each treatment are

$$SS_t = \sum_{i=1}^{a} \sum_{j=1}^{n} y_{ij}^2 - \frac{y^2}{N}$$

And

$$SS_{treatments} = \sum_{i=1}^{a} \frac{y_i^2}{n} - \frac{y^2..}{N}$$

The mean square of treatments ratio is

$$MS_{Treatments} = \frac{SS_{Treatments}}{(a-1)}$$

The error mean square is

$$MS_E = \frac{SS_E}{[a(n-1)]}$$

The error sum of squares is obtained by subtraction as

$$SS_E = SS_T - SS_{Treatments}$$

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0
Treatments	$SS_{Treatments}$	$a-1$	$MS_{Treatments}$	$\frac{MS_{Treatments}}{MS_E}$
Error	SS_E	$a(n-1)$	MS_E	
Total	SS_T	$an-1$		

Table 2.1 The Analysis of Variance for a Single-Factor Experiment, Fixed – Effects Model (Montgomery et al., 2002)

2. Factorial Experiment

Factorial Experiment is a technique for the experiment included two or more factors that each complete trial or replicate of the experiment all possible combinations of the levels of the factors are investigated. The observations and replicates may be described by the linear statistical model as follow.

$$Y_{ij} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \epsilon_{ijk} \begin{cases} i = 1,2,\dots,a \\ j = 1,2,\dots,b \\ k = 1,2,\dots,n \end{cases}$$

Where y_{ij} is the total of the observations in the ijth, μ is the overall mean effect, τ_i is the effect of the ith level of factor A, β_j is the effect of the jth level of factor B, $(\tau\beta)_{ij}$ is the effect of the interaction between A and B, and ϵ_{ijk} is a random error component having a normal distribution with mean zero and variance σ^2.

The analysis of variance can be used to test hypotheses about the main factor effects of

A and B and the AB interaction. The hypotheses of the experiment are

1. $H_o: \tau_1 = \tau_2 = \dots = \tau_a = 0$
   H_1: at least one $\tau_i \neq 0$ (no main effect of factor A)
2. $H_0: \beta_1 = \beta_2 = \dots = \beta_b = 0$
   $H_1: at\ least\ one\ \beta\_j \neq 0$ (no main effect of factor B)
3. $H_0: (\tau\beta)_{11} = (\tau\beta)_{12} = \dots = (\tau\beta)_{ab} = 0$
   H_1: at least one $(\tau\beta)_{ij} \neq 0$ (no interaction)

The sums of squares computing formulas in a two-factor analysis of variance (ANOVA) are

$$SS_t = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} y_{ijk}^2 - \frac{y^2 \ldots}{abn}$$

$$SS_a = \sum_{i=1}^{a} \frac{y_i^2 \ldots}{bn} - \frac{y^2 \ldots}{abn}$$

$$SS_B = \sum_{j=1}^{b} \frac{y^2 .j.}{an} - \frac{y^2 \ldots}{abn}$$

$$SS_{AB} = \sum\sum \frac{y_{ij}^2}{n} - \frac{y^2 \ldots}{abn} - SS_A - SS_B$$

$$SS_E = SS_T - SS_{AB} - SS_A - SS_B$$

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0
A treatments	SS_A	$a-1$	$MS_A = \frac{SS_A}{a} - 1$	$\frac{MS_A}{MS_E}$
B treatments	SS_B	$b-1$	$MS_B = \frac{SS_B}{b} - 1$	$\frac{MS_B}{MS_E}$
Interaction	SS_AB	$(a-1)(b-1)$	$MS_{AB} = \frac{SS_{AB}}{(a-1)(b-1)}$	$\frac{MS_{AB}}{MS_E}$
Error	SS_E	$ab(n-1)$		
Total	SS_T	$abn-1$	$MS_E = \frac{SS_E}{ab(n-1)}$	

Table 2.2 ANOVA Table for a Two-Factor Factorial. (Montgomery et al., 2002)

From F-distribution with $v_1 = a-1$ and $v_2 = ab(n-1)$ degree of freedom, if $H_0: \tau_i = 0$ is true. The null hypothesis is rejected at α level of significance if $f_0 > F_{\alpha,a-1,ab(n-1)}$ that mean factor A is significantly affected to the result.

With $v_1 = b - 1$ and $v_2 = ab(n-1)$ degree of freedom, if $H_0: \beta_j = 0$ is true. The null hypothesis is rejected at α level of significance if $f_0 > f_{\alpha,b-1,ab(n-1)}$ that mean factor B is significantly affected to the result.

With $v_1 = (a-1)(b-1)$ and $v_2 = ab(n-10)$ degree of freedom, if $H_0: (\tau\beta)_{ij} = 0$. The hypothesis is rejected at α level of significance if $f_0 > f_{\alpha,(a-1)(b-1),ab(n-1)}$ that mean the interaction between A and B is significantly affected to the result.

3. Model Adequacy Checking

To assess model adequacy, the residuals from a factorial experiment can be used. [14] The residuals from a two-factor factorial are the difference between the observations and the corresponding cell averages.

$$e_{ijk} = yijk = \bar{y}_{ij}.$$

From the normal probability plot of the residuals, the residuals that do not fall exactly along a straight line passing through the centre of the plot indicate some potential problems with the normality assumption.

2.2 Car Repainting System

2.2.1 Paint Colour

Car painting colour consists of four compounds as shown in Figure 2.4.

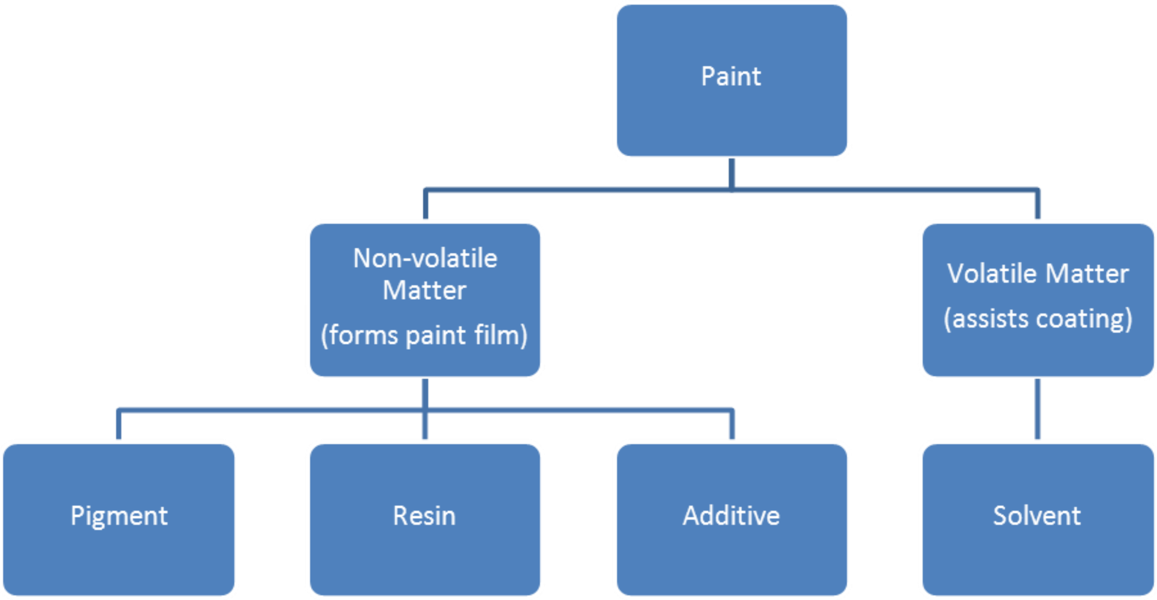


Figure 2.4 Colour Components

- Pigment are substances that appear as various colours to what used to coat and looks like a powder generally has two functions, beauty and durable. Pigments have the ability to spread and some have the ability to cover the surface of the object well. Most pigments are insoluble in any solvent. Therefore, the implementation will need to he ground it that small particles of the colour powder suspended in Resin.
- Synthetic Resin refers to the type of plastic material. It generally produced by the polymerization process that is more durable than natural resin. Resin is responsible for retaining the particles of pigments together with the adhesion between the layers of paint to the surface coating.
- Solvent is responsible for adjusting the viscosity of the colour suitable for implementation. That after the paint and the solvent to evaporate completely. There are only the colour pigments and resins as a colour film left on the painted surface.
- Additive is a substance put in to the colour to improve the properties of colour, in terms of production and properties of colour film such as reducing dry time or deforming and prevent bubble in colour film. The average volume is about 0.3%

depending on the manufacturer. Although the additive is used in small amounts, it is necessary to improve the properties of colour.

2.2.2 Colour Film Properties Inspection

1. Wet Paint Properties Inspection

1.1 Fineness of Grind

The Fineness of Grind Gauge is used for the determination of the wet film thickness at which the size of the pigment just exceeds the film thickness indicated by the minimum depth of the measurement of pigment that are visible through a split.

Fineness of Grind consists of two parts.

1. The gauge consists of hardened steel about 175 mm long, about 65 millimetres wide and about 13 mm thick. Smooth and flat surface of the gauge have one or two grooves. Each groove has a depth from the highest to lowest, such as from the 50 or 100 microns deep at one end to 0 microns at the other end with a depth indicator.

2. Scraper is a sharp edge steel about 90 mm long, about 40 mm wide and 6 mm thick as shown in Figure 2-5.

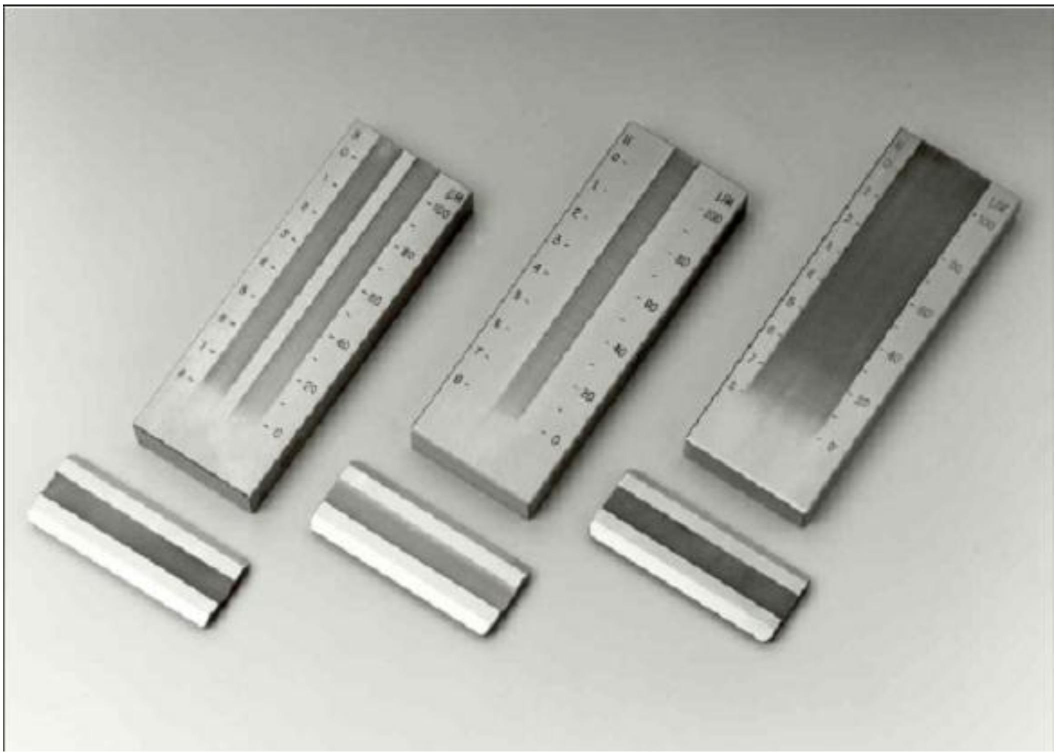


Figure 2.5 Fineness of Grind (ElektroPhysik USA Inc, 2010)

Method of use

According to ASTM-D 1210 Standard (ASTM, 2010), the selected gauge should be clean and dry and placed on a flat surface. A small sample of the test material is poured into the deep end of the groove, and then with the scraper blade held at right angles to the gauge with both hands, it is scraped at a steady rate down the length of the gauge. Sufficient downward pressure should be exerted on the scraper to clean the level surface of the gauge but leaving the channel filled with material. Immediately after draw down determine the fineness-of-grind by viewing the gauge, at right angle to its length, at a grazing angle. Observe the point along the channel where the material first shows a predominantly speckled appearance and note the graduation marks between which the number of particles, in a band 3mm wide across the groove, is in the order of 5 to 10. Report the higher graduation figure as the fineness-of-grind, disregarding any scattered specks which may appear above the band where the speckles appearance begins.

1.2. Viscosity

Viscosity is often defined differently depending on the type of colour. Instrument used to determine the viscosity is Stormer Viscometer that determines viscosity as a function of time required for a definite number of revolutions of a rotor immersed in sample, under a constant driving force.

Figure 2.6 Stormer Viscometer (Thomas Scientific, 2009)

Method of use

Pour sample colour into a container that is the component of the machine. Place the container on pad by dipping the blades in the sample to the limit Top propeller shaft. Before the test, rotate the rotor approximately 100 times in 25-30 seconds. Then, select the right weight for the time it takes to rotate 100 cycle rotor in 27-30 seconds. Start the test by the rotating rotor at least 10 cycles before timer.

To read viscosity, Viscosity is measured in Kreb Unit by using interpolation from the sample table, for example, Weight 125 grams measured for 30 seconds per 100 cycles, the read viscosity is 57.

Second/100 rounds	75	100	125	150	175	200	225	250	275	300	350
24	42	52	-	65	-	75	-	83	-	90	-
25	45	54	-	66	-	76	-	84	-	90	-
26	47	56	-	68	-	78	-	85	-	91	-
27	49	57	63	69	74	79	83	89	92	95	97
28	51	59	65	70	75	80	84	87	90	93	96
29	53	60	66	71	76	81	85	88	91	94	97
30	54	61	67	72	77	82	86	89	92	95	98
31	55	62	68	73	78	82	86	90	93	95	98
32	56	63	69	74	79	83	87	90	93	96	99
33	57	67	70	72	80	84	88	91	94	96	99

Table 2.3 Kreb Stormer with Interpolation in Gram.

However, viscosity changes when the temperature of the colour changes. Therefore the viscosity has to be specified with temperature, such as KU = 67/30° C.

2. Paint Film Properties Inspection

2.1 Film Thickness

Film thickness meter measures all coatings on metallic substrates using the magnetic induction. Thickness measurement is measured in microns by placing the meter on the painted surface.

Figure 2.7 Film thickness meter (Paint Test Equipment, 2009)

2.2 Gloss

The gloss value is determined by directing a light that has a similar wavelength to the human eye, at the test surface and measuring its reflection. Gloss can be measured with angles of 85°, 60° and 20°.

- The 60° angle is universal for all of film.
- The 20° angle gives improved differentiation of measurement on high-gloss film that its gloss value is higher than 60 with 60° angle measuring.
- The 85° angle give improved differentiation of measurement on low-gloss film that its gloss value is lower than 30 with 60° angle measuring.

Figure 2.8 Stargloss gloss meter (Paint Test Equipment, 2009)

Method of use

Choose the measured degree angle. Place the Gloss meter onto the object to be measured. The reading will be held on the display until another reading has been taken. Always ensure that the surface being measured is flat, and large enough to cover the oval measuring hole. For the highest accuracy of measurement, the gloss meter has to be calibrated before measuring. The calibration is carried out by measuring Gloss Standard Sheet and set its value to 91.8.

2.3 Compressed air system and painting environment

Since the first blower machine was built by Wikinson around 1776, compressed air forms an essential supplement to several industries. In car painting, compressed air is one of the key factors for high quality painting work. In this thesis, compressed air system will be focused to reduce the defects in car painting.

2.3.1 Components of air

Air is a mixture of different permanent gases amongst which nitrogen, oxygen, argon and carbon dioxide predominate. In addition to the permanent gases, air also contains water vapour in varying quantities.

Gases	Volume (%)	Weight (%)
Nitrogen	78.3	75.47
Oxygen	20.99	23.2
Carbon Dioxide	0.03	0.046
Hydrogen	0.01	0.001
Argon	0.933	1.286
Helium	0.0005	0.00007
Neon	0.0018	0.0012
Krypton	0.0001	0.0003
Xenon	0.00001	0.00004

Table 2.4 Components of Air (Domnick Hunter, 2008)

2.3.2 Contamination in Air

Depending on locality, climate and season, mainly three components, solids, water content and oil residues contaminate compressed air after compression to a considerable degree. (Domnick Hunter, 2008) One therefore finds all impurities of the ambient air in compressed form in the compressed air unless they had been eliminated beforehand. These are joined by further substances originating from the compressor itself or from the piping and compressed air hoses.

If a compressor draws in 8 m^3 of air in order to covert this into 1 m^3 of compressed air at a pressure of 8 bars, then all contaminants present in atmospheric air likewise become compressed and are therefore present in the compressed air in 8-fold concentration.

The solution to improve air quality is not restricted to the air purification chain after compression but affects all units of the compressed air system, starting with the compressor air intake right up to the point of use.

1. Solids

Dust represents solids of various kinds, forms, structure and density and can be subdivide in accordance with particle size. Dust is created in a natural manner through weathering and decay, putrefaction and fires, or through everyday human activities or through highway and railway traffic, from industrial activities in cement works or the chemical industry.

When investigating the vertical distribution of dust, it was found in areas of high concentration that the first dust layer was about 3-4 m above the earth's surface in the form of traffic dust, with a second layer above which contained mainly heating dust. Depending on particle size, dusts are subdivided into 3 classes: (Parker, 2007)

- Coarse dust grain size > 10 μm
- Find dust grain size 1 – 10 μm
- Finest dust grain size <1 μm

From amongst these three groups, it is essentially only the finest dusts which have to be counted among the floating substances.

Finest dust very often forms by far the largest share of the solids floating in air. These often form 80 – 90% (by weight) of the contaminants in air. The majority of these particles are smaller than 1 mm. The sinking speed of dust depends on the grain size. If the air is at rest, the distance fallen may amount to fractions of a millimetre for very find dust whereas, for very coarse dust, falling may take place at more than 1 m/s.

The dust content of air is influenced largely by the geographical situation and the location of the point of measurement, as well as by weather conditions such as wind, rain and snow.

Location	Medium Medium Concentration (Mg/m3)	Average Average Particle Size (μm)	Largest Largest Particle Size (μm)
Rural Area			
During Rain	0.05	0.8	4
Dry Weather	0.15	2	25
Large City Area			
Residential	0.4	7	60
Industrial	0.75	20	100
Industrial Area	3	60	1000
Workshops	1 - 10	-	-
Fettling Shop, Foundry	50 - 100	-	-
Cement Factory	100 - 200	-	-
Combustion Flue Gases	1000 – 15000	-	-

Table 2.5 Average Dust Content in Air (Domnick Hunter, 2008)

Further solid particles not originally forming part of air consist of oil soot, scale, rust as well as products of metal abrasion. Theses solid particles originate from the compressor or can be released from the internal walls of the pipework. Solid particles and lubricating oil or grease act on pneumatic installations like an abrasive paste, causing particular trouble such as wear at sensitive points. Dust particles from castings, formed when cutting metal with machine tools, are particularly abrasive in their effect.

2. Moisture in Air

Ambient air always contains moisture to varying degrees. This moisture mixes with the compressed air in the form of invisible water vapour to float in air as finely divided droplets of varying size. For this reason, aerosols are divided into two groups.

Spray: Liquid particles with a diameter of 10 μm or more are referred to as spray. Spray can be relatively easily removed from compressed air by means of various mechanical separators.

Mist: Liquid particles with a diameter of 10 μm or less are described as mist. The term mist or aerosol is applied to droplets the mass of which is so small they can remain in suspension in the gas stream. Mist can only be removed from compressed air steam with great difficulty and calls for finer filter systems.

Mist or fog arises in the following manner:

Separation effect of mist

	Brownian Movement	Inertia Effect	Blocking Effect
Surface Speed (m/min)	5 – 12	120 – 150	120 – 150
Performance Particle < 3 μm	Practically 100%	Practically 100%	Practically 100%
Performance Particle > 3 μm	55 – 99%	90 – 98%	15 – 30%

Table2.6 Separation effect of mist (Domnick Hunter, 2008)

The quantity of vapour, which can be contained by 1 m^3 of air, is limited and depends solely on the temperature of the air. The water vapour mixes with the air as a gaseous component. At high air temperatures, a relatively large quantity of vapour, up to saturation point, can be carried.

Every kilogramme of air contains a certain quantity of water in grams. This value x in g/kg is the absolute air humidity or also degree of humidity and is a result of the ratio of the quantity of water picked up to mass of dry air.

Air with a maximum concentration of water vapour is saturated. If the air contains less vapour, it is unsaturated and can pick up further water vapour right up to the saturation limit. If the air contains more water vapour than corresponds to the degree of saturation, the surplus vapour precipitates in the form of water mist until the new saturation point is reached.

The temperature at which a quantity of air is saturated by water vapour is described as saturation temperature or dew point temperature. In the other word, the dew point is that air temperature at which gaseous water vapour begins to condense in cooling air and is visible precipitated as dew.

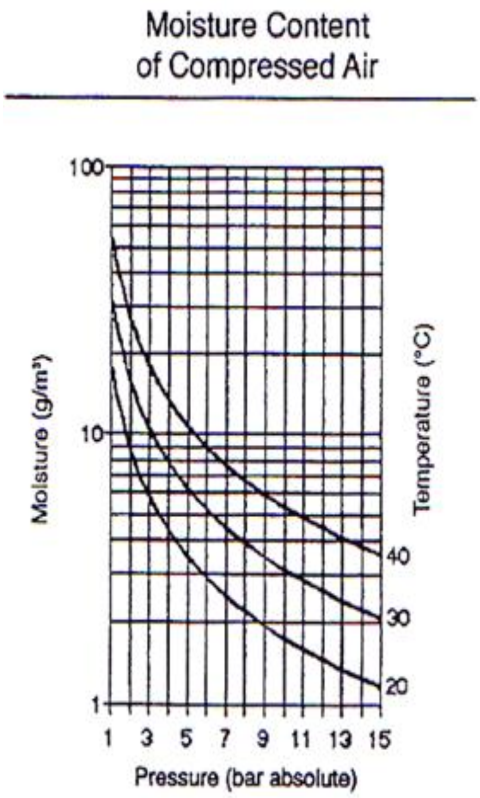


Figure 2.9 Maximum Moisture Content of Compressed Air (Domnick Hunter, 2008)

Compression also causes finest fog droplets to form in the air. These can be retained in suitable filters, giving them the opportunity to coalesce. However, filters can solely remove droplets from the air current, not gaseous water vapour. In order to remove this water vapour as well, specially designed compressed air dryers have to be fitted.

3. Hydrocarbons

Saturated hydrocarbons in air are primarily obtained from mineral oil. Crude oil is processed in refineries. Distillation is used to fractionate the crude oil into constituents of differing boiling points and drawn off separately, ranging from petrol via kerosene to lubricating oil. When these substances are used, they are released into the environment.

Sometimes a certain quantity of oil in the compressed air is desired or even prescribed. Pneumatic machines and tools receive their lubrication through a mixture of finely distributed oil added to the compressed air as an oil mist.

The presence of undesirable oils in compressed air is frequently the result of two causes: (Domnick Hunter, 2008)

1. The air drawn in by the compressor already contains some oil. This introduction of oil can be avoided or diminished by locating the intake filter into the open air, however protected against rain and dust, or finding an optimum location for the compressor itself.

2. The compressor passes oil into the compressed air, such as with piston compressors where the lubricating oil helps to form a seal between piston and cylinder wall. This film of oil is subjected to a strong shearing effect, causing oil particles to be detached from the interface between piston and cylinder wall and to enter the compression space.

In addition, oil or grease contamination arises from directional control valves, cylinders and regulators, which may have been greased or oiled before dispatch.

By far the largest share of the oil contained in compressed air, sometimes 99% or more, occurs as floating droplets. Their diameter is usually less than 0.8 mm and even as low as 0.1 µm.

For rotary screw compressors, oil is intentionally added to the drawn in ambient air when compression takes place. The residual oil content at the pressure outlet of screw compressors amounts, as a rule, to about 3 – 15 mg/m^3. Not only with oil injected screw compressors but also with established types of piston or vane compressors, oil is used for cooling and lubrication. Whereas oil injected screw compressors reach a maximum oil temperature of about 85 – 90 °C, the oil of piston compressors or rotary vane types reaches far higher temperatures.

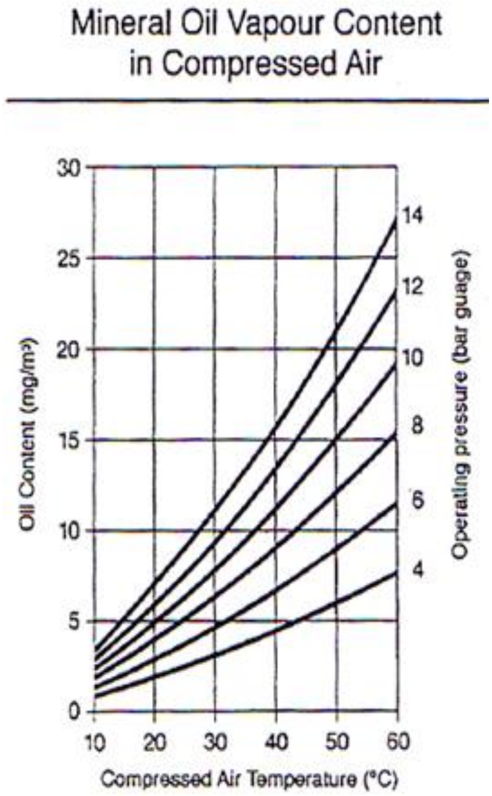


Figure 2.10 Maximum Mineral Oil Vapour Content in Compressed Air (Domnick Hunter, 2008)

2.3.3 Separators and Filter Systems

Separators and filters are basic requirements of a compressed air system.

1. Separators

The size of the mist droplets is of great importance where separation is concerned. The droplet diameter, the viscosity of the liquid droplet and the density of the air determine the setting speed of the liquid droplets in the air at rest.

Diameter	Speed
0.1mm	24 m/s
0.01mm	0.3 m/s
0.001mm	0.003 m/s

Table 2.7 Viscosity of the droplets (Domnick Hunter, 2008)

In order to force mist droplets into motion, considerable forces have to be applied. In order to achieve this, the mist laden air is caused to change direction, allowing strong inertial forces to affect the mist droplets. These forces drive the droplets through the air with elevated relative speed. The velocities so achieved are directly proportional to the forces, i.e. a force of 10 times the weight of the droplet increases the velocity to 10 times the setting speed. The high acceleration values needed for droplet separation from compressed air can, for example, be achieved through a sharp diversion of fast flowing air, causing larger liquid particles to be projected out and separated.

Depending on the purpose of the compressed air application the separator is selected to achieve optimum degree of purity in line with requirements. The most important mechanical separators used by industry are: (Parker, 2007)

- Cyclone or Vortex Separators: Cyclone separators are coarse separators fitted with a spinning device. The latter causes an extremely high radial acceleration with correspondingly high centrifugal force to arise, so that a rotating air current is formed inside the cyclone separator. These centrifugal forces can rise to a multiple of the weight of the droplet itself. Through the centrifugal force thus created, solid particles as well as oil and water droplets are projected against the inner separator wall and, driven by gravity, flow downwards into the separator bowl. The separating efficiency of a cyclone amounts to about 98 – 99%, the droplet limiting size is around 10 – 50 μm.

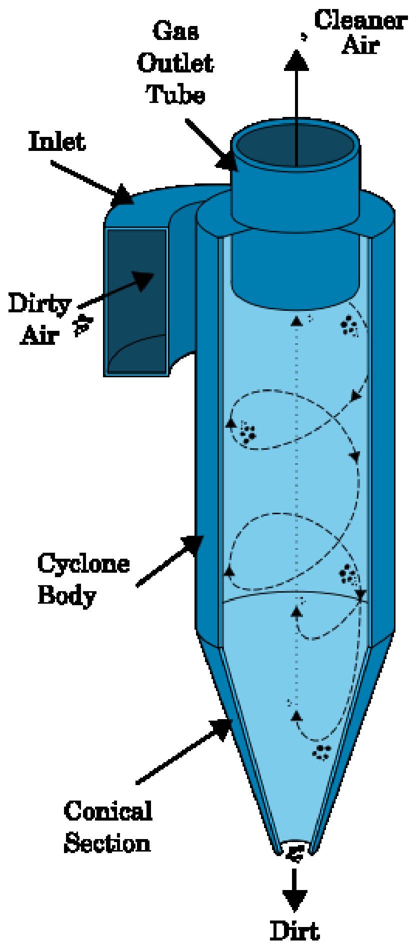


Figure 2.11 The Cyclone Separator (Lenntech, 2009)

- Impingement separators: Impingement separators are normally used if liquid droplets with a very fine range of droplet size have to be separated from the air flow. Impingement separators tend to become blocked and must, therefore, be regularly flushed. The mist droplets are caused to change direction rapidly whereupon their inertia causes them to collide with a surface, thus separating them from the gas stream. Impingement separation separates out droplets from within a relatively narrow range of diameters. With vertical impingement, separation is effective for droplets of about 40 µm limiting size, with horizontal approach flow down to about 10 – 20 µm

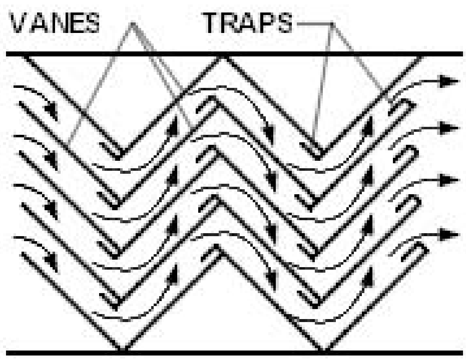


Figure 2.12 Impingement Separators (KingTool Company, 2010)

- Cyclonic Separators: Cyclonic separators are a particular design of cyclones. Ass axial cyclones without flow reversal, these separators are used for coarse operations, and tend to be employed when the disposal of considerable quantities of liquid in the form of large droplets from the compressed air system, if required and may also contain solid particles.
- Wire Mesh: This separator has considerably reduced in recent years. Because of the danger of becoming blocked, separating systems of this type have to be flushed periodically. The pressure losses depend greatly on the degree of liquid loading. Packages of wire mesh are capable of achieving a degree of separation of 99.9%, given droplets of 6 – 20 μm limiting size.

2. Filter

Filtration removes extraneous substances from the compressed air. Dust and fog is filtered out of the compressed air on the suction side of the compressor. Filters achieve separation efficiencies of up to 100% for particle sizes down to about 1 μm. In order not to overload these fine filters with coarse particles, mechanical coarse matter separators are fitted prior to the fine filters. The two types of filters are: (Domnick Hunter, 2008)

- Surface filters: The screening or sieving effect plays the primary roles as separating mechanism. Impurities (as long as they are larger than the specified pores) are separated out on the surface of the filtering material and form a filter cake in the course of the service life. As a consequence of this, there is the side effect that, to a small extent, smaller particles than the effective pore width can also be separated. As the impurities are deposited mainly on the surface, a simple regeneration of filter elements of this design is possible.

Figure 2.13 Surface filters (Domnick Hunter, 2008)

- Depth filter: Depth filtration makes use of fibre beds consisting of a maze of the finest individual fibres. There are, therefore, no specific pore sizes. Such filter materials act not only as a sieve, mainly retaining particles corresponding to the pore size, but also separate impurities which are considerably smaller than the fibre maze structure.

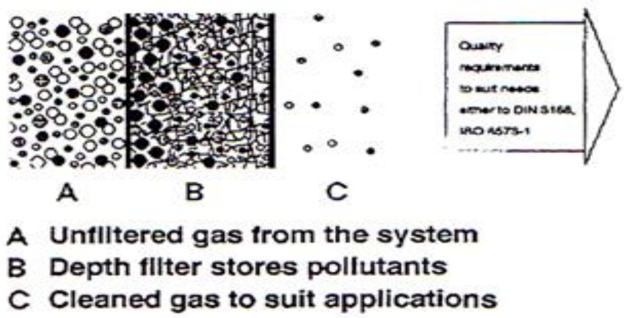


Figure 2.14. Depth Filter (Domnick Hunter, 2008)

3. Oil Separation

When using an oil lubricated compressor without filtration, oil enters the connected compressed air network with an assumed concentration of c = 10 mg/m^3. With an efficient depth filter, a residual oil concentration of 0.01 mg/m^3 is achieved that it is technically defined as oil free compressed air. ISO 8573.2 standard gives the user a means of determining oil aerosol content as shown below.

Class	Oil Content mg/m^3
1	0.01
2	0.1
3	1
4	5
5	25

Table 2.8. ISO 8573.2 (ISO, 2007)

- Oil Droplet Separation

  Oil droplet is a result of condensed Oil vapour by simple cooling. The condensed oil upon cooling precipitates on the internal walls of the compressed air line, and is separated to nearly 100% if the usual depth filters are fitted, and will flow into the bottom of the filter. The oil content in aerosol form, the oil mist concentration, before and after the filter, is of primary significance.

- Oil Mist Separation

  Oil mists comprise the very finest droplets in a system, and are visible as aerosols. Modern compressors are usually fitted with air or water cooled after coolers that the temperature of compression is reduced to a low operating temperature after the compressor. In the course of this cooling process hydrocarbons are, condensed. The residual oil content varies as a rule between 5 – 20 mg/m^3, depending upon compressor design and can be separated by appropriate filter.

- Oil Vapour separation

Oil Vapour is present as a molecule in the compressed air and is thus not separated out by mechanical filters. The quantity of oil vapour depends on the temperature.

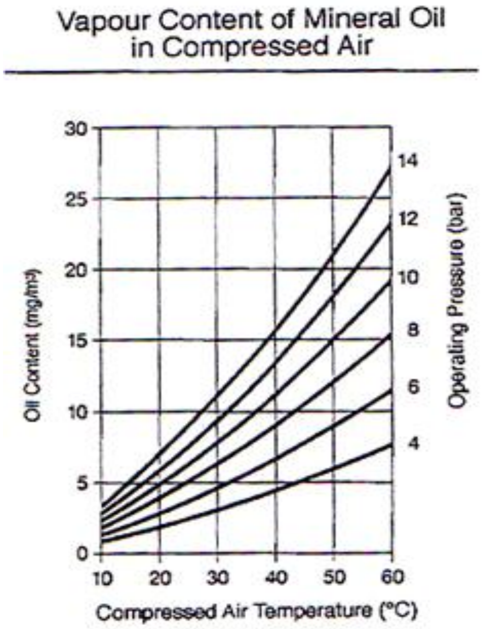


Figure 2.15. Vapour content of Mineral Oil in Compressed Air (Domnick Hunter, 2008)

The oil vapour remaining in compressed air is reduced by the use of activated charcoal adsorption filters. Residual oil contents down to 0.003 mg/m^3 can be achieved. Compressed air treated to this extent can be granted as technically oil free. The claimed residual oil content is achieved only if the operating conditions are adhered to. Optimum separation requires: - (Domnick Hunter, 2008)

- A low inlet temperature to the adsorption filter
- Relative humidity of the compressed air of about 60% maximum
- Pre-filtration with a depth filter

The service life of activated charcoal elements is limited with regard to oil vapour adsorption. The service lives of 300-1000 operating hours are realistic, given optimum separation under normal conditions of use.

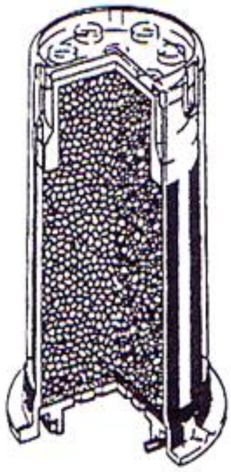


Figure 2.16. Ground Activated Charcoals (Domnick Hunter, 2008)

2.3.4 Compressed Air Dryers

The drying of compressed air is carried out by a variety of processes. Compressed air drying, working on the principle of cooling and condensation, makes use of refrigeration systems. Pressure dew points of down to 2ºC are achieved by these methods. Pressure dew points below the limit value 0ºC cannot be reached by the principle of condensation.

Compressed air dryers operating on the principle of adsorption can achieve pressure dew points below 0ºC. Drying compressed air through adsorption represents a purely physical process in the course of which water vapour is bound to the drying medium (adsorbent) through binding forces of molecular adhesion. Adsorbents are solids in spherical or granular form which are permeated by a multiplicity of pores. The water vapour is deposited onto the internal and external surface of the adsorption medium such as Silica gel(SiO_2) or Activated alumina (Al_2O_3), without the formation of a chemical compound taking place, therefore the adsorption medium does not have to be replenished but only regenerated periodically.

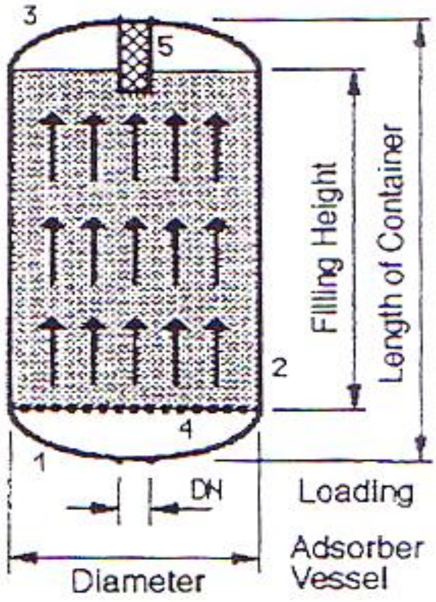


Figure 2.17. Adsorption side (Domnick Hunter, 2008)

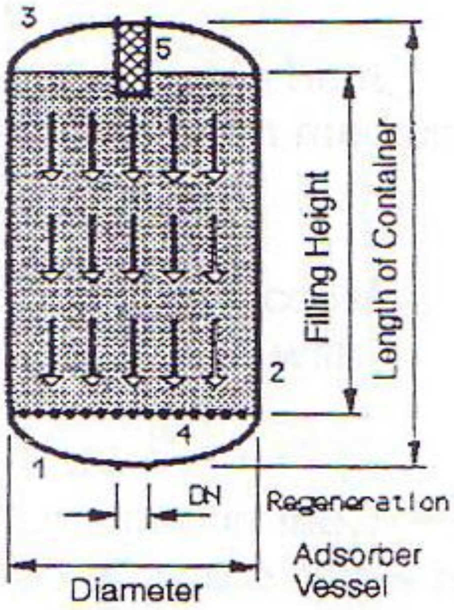


Figure 2.18.Regeneration side (Domnick Hunter, 2008)

A filter should be installed upstream of the dryer in order to eliminate condensate, oil droplets and solid particles, a filter downstream from the dryer to remove any abraded matter from the absorber.

CHAPTER III

PROBLEM DESCRIPTION

In the process of defining the problem, begins with brainstorming in the team to analyse the current problems in the painting process. The diagram of the process must be done carefully in every step to identify key process input variables and results in the process output.

This step is like an examination of the process which knows what the real cause of failure or defect in the production affecting product quality. This step led to the analysis of the problem experimental and hypothesis or by using statistical information that is collected properly. The plan of the product flow is essential to identify the source of defects and hidden problem in the production processes, resulting in loss of time, money and customer satisfaction.

3.1 Determine team of operation

To set team in the research, it requires people with knowledge and expertise in the painting production to brainstorming and experiment with the equipment and techniques in order to achieve the goal of this research. Teams consist of person from various departments as follows.

1. Team leader
2. Manager
3. Body & Painting department supervisor
4. Painter

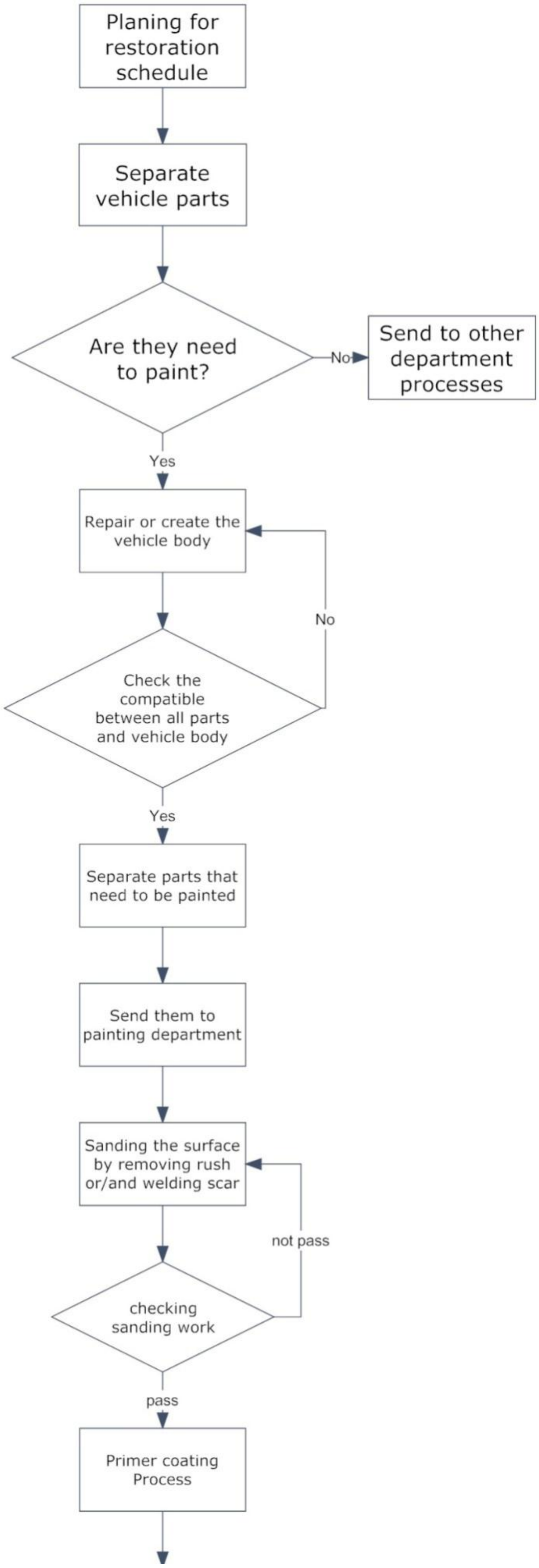
3.2 A Study of the Processes

The process of vintage car restoration can be described by the diagram shown in Figure 3.1 that described in detail as follows.

1. After a car is received, collaborate with other department to planning for the restoration schedule in each process and scheduling the work plan which can

be operated concurrently such as spare parts ordering and chromium plating while the car body is in the spray painting step

2. Remove the parts which are not related to spray painting, for example, chromium edge, lamp, wing mirror, bumper, rubber part and mirror. If necessary, send the part to recondition such as chromium plating.
3. Repair the iron structure of the car body which is usually eroded or rusted by patching, changing or reconstruction.
4. After finish recondition the car body, reassemble the parts to verify the dimension and consonance of each part with the car body.
5. Remove the parts and dispart their structure appropriately for spray painting
6. Prepare the surface for spray painting by sanding off rust or weld the metal to make the surface consistently smooth.
7. Do primer coating to the metal.
8. Apply putty work for adjusting the metal surface of painting area to match the thickness and shape of required specification
9. Scrub the surface deliberately to prepare the surface for spraying topcoat step.
10. Spray painting process start with sealer spraying follow by sooth colour spraying (top coat)
11. Inspect the finished workings and correct it in case there is some flaw.
12. Store the workings and wait for combining with other parts.



Planing for restoration schedule
Separate vehicle parts
Are they need to paint?
No
Send to other department processes
Yes
Repair or create the vehicle body
No
Check the compatible between all parts and vehicle body
Yes
Separate parts that need to be painted
Send them to painting department
Sanding the surface by removing rush or/and welding scar
not pass
checking sanding work
pass
Primer coating Process

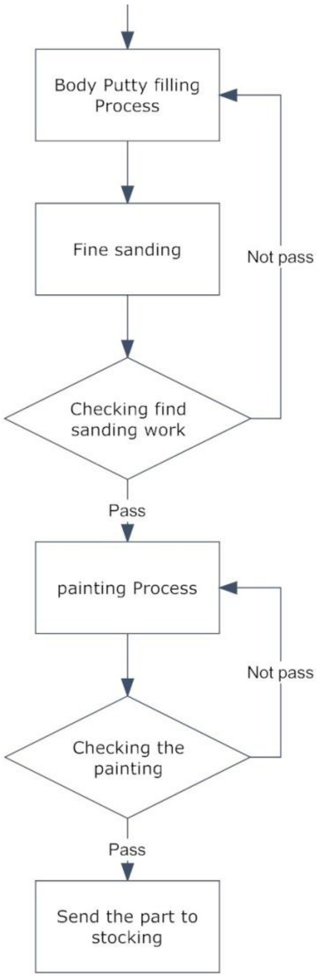
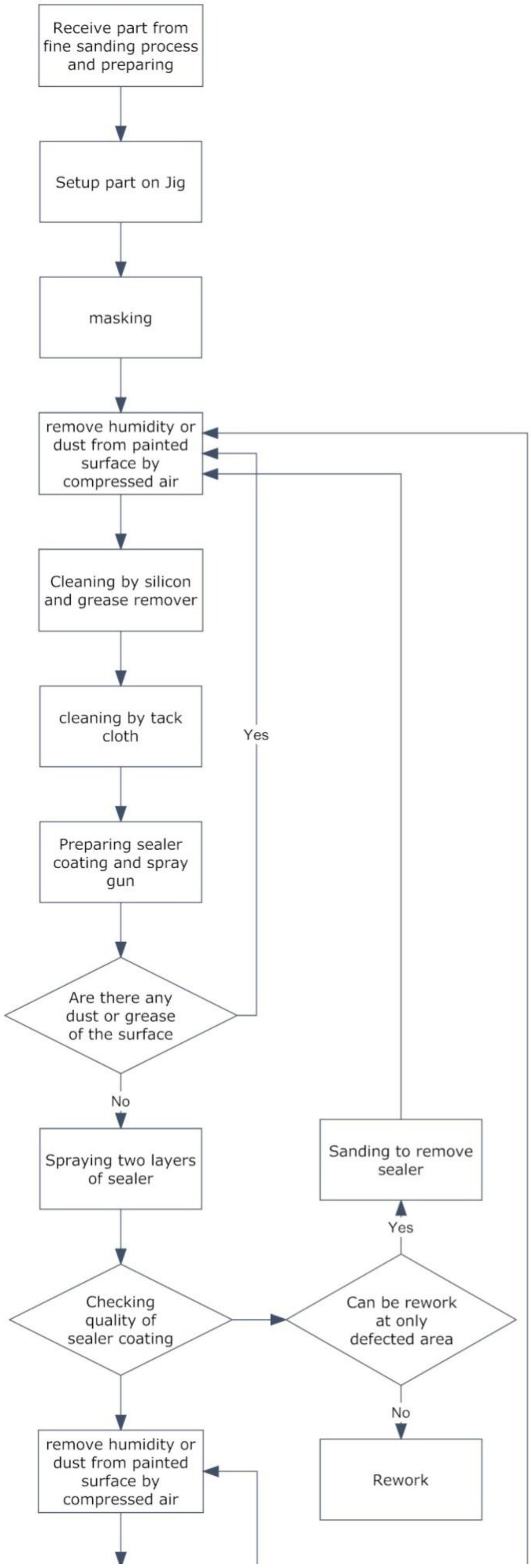


Figure 3.1 Flow chart of Restoration Processes

This research is focused on researching and improving topcoat painting process to reduce defect in the paint work. The details in painting processes are shown as follows.


Receive part from fine sanding process and preparing
Setup part on Jig
masking
remove humidity or dust from painted surface by compressed air
Cleaning by silicon and grease remover
cleaning by tack cloth
Preparing sealer coating and spray gun
Are there any dust or grease of the surface
Yes
No
Spraying two layers of sealer
Checking quality of sealer coating
Can be rework at only defected area
Yes
Sanding to remove sealer
No
Rework
remove humidity or dust from painted surface by compressed air

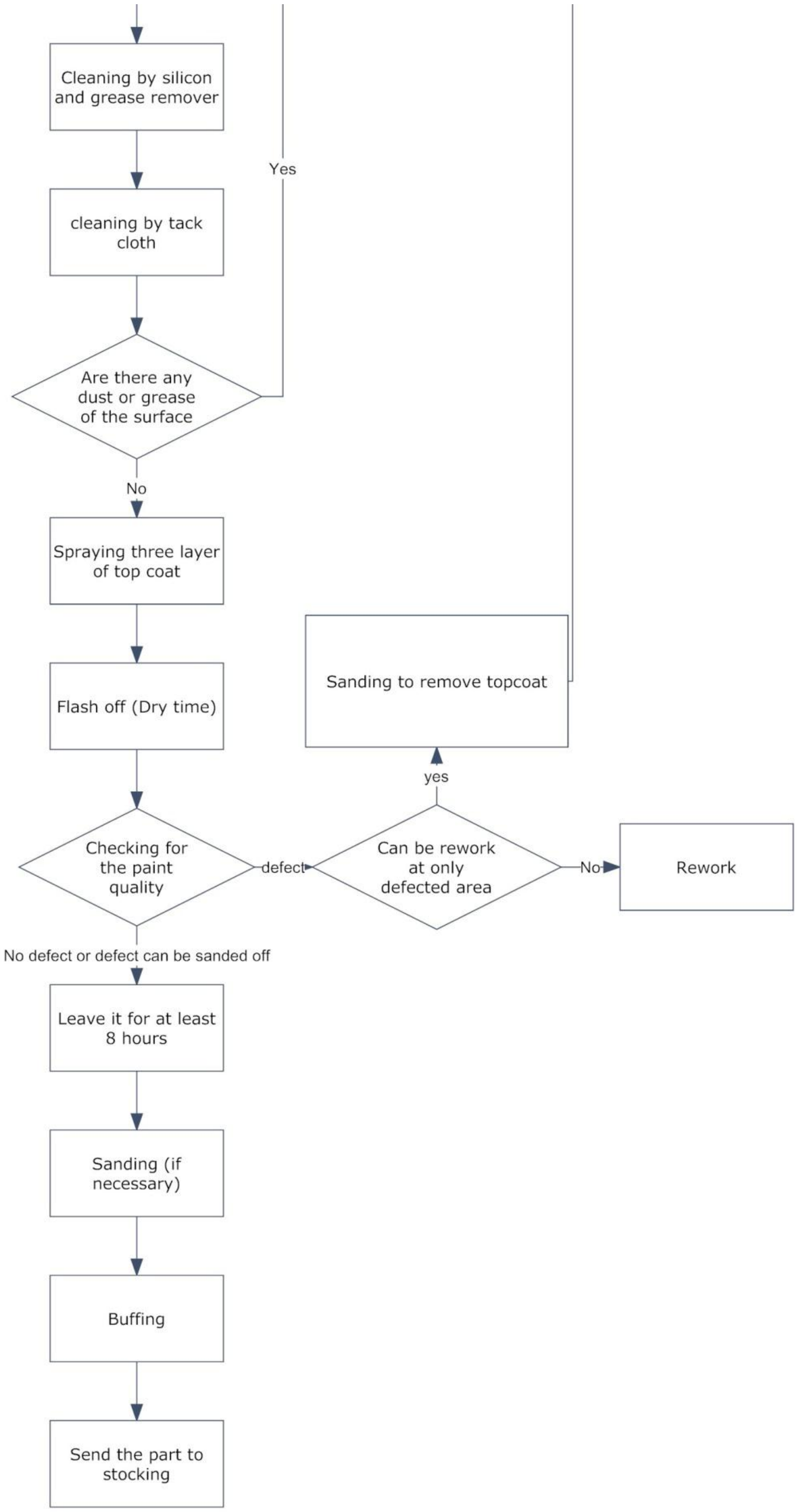


Figure 3.2. Flow chart of Painting Processes

From the research, the processes in painting department are described as follows.

1. Preparing for spray painting step

1.1 Receive the part from previous process and draw the colour according to the code and other requisite chemical solution. Before request the material, spray painting worker must check the workings to find any flaw and verify that the part is ready for spray painting. For the simple flaw, the spray painting worker may revamp by himself such as use the sandpaper sanding the workings in the problematic area. Then the supervisor will check the workings after finishing the repairing step.

1.2 Spray painting worker bring Jig to equip in the spraying room to match the part. Then, he will put the part on the Jig and check for the stability between Jig and part.

1.3 Mask the area that will not be sprayed by using the masking paper to cover the unwanted area with sticky tape.

1.4 Start cleaning the part by blowing the air to eliminate the dust and moisture on the part surface.

1.5 Pour Silicon and Grease Cleaner in clean white fabric and apply to the spray painting area to remove grease on the surface.

1.6 Apply tack cloth all over the spray painting area to trap the dirt for the last step.

2. Spray painting step

2.1 Painter mix sealer and spray gun.

2.2 Check the cleaning of the painting area again to confirm that there is no dust or blemish. If necessary, go back to step 1.4

2.3 Spray the sealer from spray gun on the surface 2 times and leave the sealer to dry for 15 minutes.

2.4 Check the workings after sealer spraying for any flaw.

2.5 Identify that the flaw could be corrected by sanding some area and spraying the sealer again or must be corrected by rework.

2.6 Before apply the spray painting, the part will be cleaned as mentioned in 1.4 – 1.6 step again until the spray painting surface is deprive of dust and blemish.

2.7 Spray top coat by spray gun all over the part 3 times and leave the colour film to flash off to the phase that the dust will not adhere the film surface about 1 hour. Then, leave the colour film for total 8 hours before checking the quality of spray painting.

2.8 If the workings are not passed the quality check, the part will be sent to sanding and recheck. If sanding cannot correct the problem, the part will be sent to sanding the top coat off and then apply the spray again or rework. The supervisor will be the verifier with the painter.

2.9 Glaze the workings and store for the coming assembling

* In the job process, there might be many workers to spray one part up to type and characteristic of the workings.

3.2.1 Spray painting consists of the following 4 major steps:

1. Sealer coating process

Sealer forms a sort of barrier between the undercoat and top coat that the materials and solvents in subsequently applied paint top coats can't penetrate it and attack the substrate, add maximum adhesion capabilities for top coats and provide a uniform colour of top coats. Especially, because of Thailand hot weather, a slow solvent is used in the top coat mixing to help it lay out that the slow solvent will attack sensitive substrate

2. Top coat painting process

The colour used in this process is solid colour which has no Aluminium flake in the colour. The solid colour is used for almost vintage car.

3. Quality checking step

After the spray painting and flashing off step for appropriate period, the spray painting workers and supervisors who are the expert in workings inspection will verify the quality of workings by looking and light projecting at the same time and touch the workings all over the piece to discover the defects and mark for correction.

4. Repairing and correction step

Sanding will be applied when there is discovery of the defects from painting. There are 3 categories of repairing and correction as follows:

4.1 Flaw that can be corrected by sanding which is the flaw which has an effect on surface of the painted film that is not deep to the next level or surface of the part. For example, dust that adhere to the surface of the film can be corrected by sanding the film surface to eliminate the dust in sealer spraying process or top coat process.

4.2 Flaw that can be corrected by sanding the surface of the film at the flaw completely and spraying again. For instance, the flaw that is deep to the next level or surface of the part or flaw that is appeared before this step such as immense dust that immersed deeper than thickness of the film.

4.3 Flaw that need to be corrected by rework over the part such as turgid mark, which cannot get rid of by sanding the film surface, or scratch that is deep in several layer of the film.

In repairing process, painter will inform supervisor for appropriate correction method approval and checking the workings after repair every time. If the repaired workings is not met the standard, the rework is always needed.

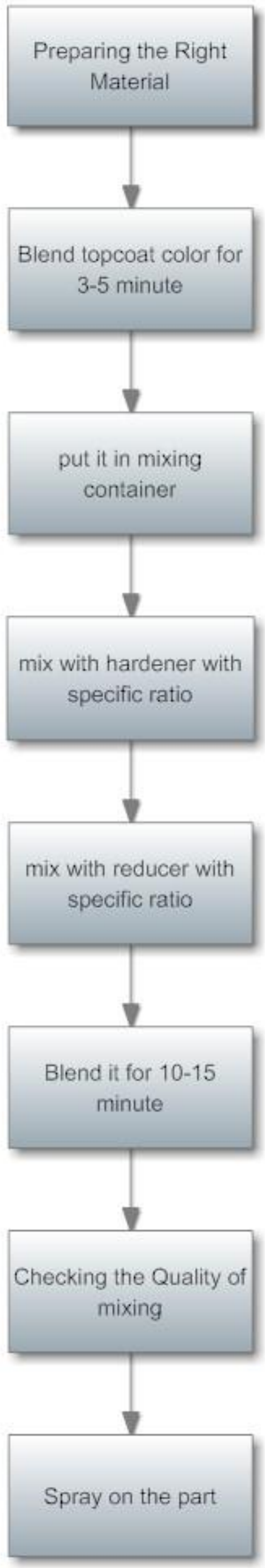


Figure 3.3. Flow Chart of mixing sealer and topcoat

In addition, from the figure 3.3, mixing the colour started with preparing the material according to standard. Open the colour can and blend the colour at least 3 – 5 minutes to make the colour consistently distributed. Then, pour the colour into mixing container by measure the volume as needed. Pour the Hardener and Reducer according to the mixing standard respectively such as 1:0.5:0.1. Then, blend the mixed colour to be harmonized for about 10 – 15 minutes. Then, check for the viscosity of the colour to align with standard.

Note:

- Equipment and container for mixing the colour must be clean, dust free and dry
- Pouring material into container must use filtered grate and filter again for 1 – 2 times before pouring in the spray gun
- In fact, painter neglects to blend mixing for 10-15 minutes. From measuring, they usually blend it for 3 minutes approximately that is mentioned in next chapter

3.2.2 Tool and Equipment in painting

Spray gun in spray painting process is suitable for different characteristic and condition of the workings. The appropriate spray gun must be chosen to match the workings. For the colour spray painting, the HVLP (High Volume Low Pressure) will be used. There are 2 types of spray gun usage according to the workings characteristic.

1. Enormous surface is matching with the spray gun that has Nozzle size 1 mm or more to make the colour distributed consistently and nice such as SATAjet® 3000. However, it is not suitable for spot correction or small workings that has complicated shape because it the too long spraying will result in many issues such as thick, blur and rough colour on the spot or area.
2. Small area or complicated shape is matching with the spray gun that has Nozzle size smaller than 1.0 mm such as SATAminijet® 3000. Applying the gun to enormous area may cause some colour issues because it has small amount of colour eject from the gun's nozzle.

The spray guns in this study are SATAjet® 3000 and SATAminijet® 3000 with the following specification:

	SATAjet® 3000	SATAminijet® 3000
Air consumption:	430 Nl/min (15,2 cfm)	115 Nl/min (4,1 cfm)
Recommended inlet pressure:	2.0 bar (29 psi)	2,0 bar (29 psi)
Maximum operating temperature:	50	50
Maximum operating overpressure:	10.0 bar (145 psi)	2,0 bar (29 psi)
Air inlet:	G 1/4 ext.	G 1/4 ext.
Nozzle Size:	1.0 - 2.2	0.3 - 1.1 (0.8 SR – 1.4 SR)

Table 3.1.Spray Gun Specification (SATA GmbH & Co., 2010)

3.2.3 Painting Booth

Painting Booth system consists of:

1. Air Supply Unit System – The system uses the air from outside to disburse in spray painting room by passing the filter for clean air. The filter is installed for filtering the dust before is disburse the air in to the room since the dust can cause the problem with dust grain and contamination on workings in the process of spraying while the colour film has not entered the flash off step yet.

2. Air Exhaust System – The system pulls the air out from the bottom of the spraying room. The system will pull the dust and air out of the spraying room to make the air in the spraying room clean and reduce the amount of dust not to scatter and adhere with the workings.

3.3 Study of Defect in painting

Spray painting is the vital process which has an effect on overall quality of renovate vintage car since the vintage car require high quality of look and feel. The good spray painting then result in customer satisfaction directly.

From the study of information and process of spray painting, founded that there are many flaws especially the problems from the dust contamination and blistering/solvent boil which are the main matter to be reduced. Moreover, it is the way to increase the company value since these problems raise high cost for repairing and applying spray painting process again. This also includes the opportunity cost lose in repairing and checking the workings. The drawback mentioned above can be described as follows:

The waste from the spray painting process collected from 32 cars which are sprayed the whole car since September 2009 to March 2010 stated that the flaw rate is 100%. Some flaw appeared in every working and some appeared sometimes as shown in the table 3.2.

Defect	Defective (per car)	Defective (% per car)
Solvent Boil / Blistering	32	100%
Dust Contamination	32	100%
Overspray	20	62%
Cratering	14	43%
Run/Sags	3	9%
Orange-Peel	1	3%

Table 3.2. Defective Rate

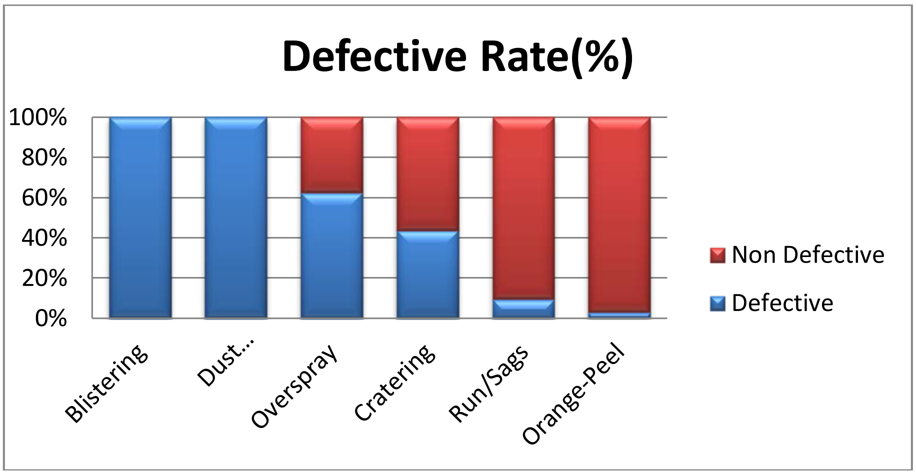


Figure 3.4 Defective Rate

The amount of waste found grouped by type per month:

	Sep 09 (4 PCS)		Oct 09 (5 PCS)		Nov 09 (7 PCS)		Dec 09 (4 PCS)		Jan 10 (3 PCS)		Feb 10 (6 PCS)		Mar 10 (3 PCS)		Total (32 PCS)	
	PCS	%	PCS	%	PCS	%	PCS	%	PCS	%	PCS	%	PCS	%	PCS	%
Solvent Boil / Blistering	4	100.00	5	100.00	7	100.00	4	100.00	3	100.00	6	100.00	3	100.00	32	100.00
Dust Contamination	4	100.00	5	100.00	7	100.00	4	100.00	3	100.00	6	100.00	3	100.00	32	100.00
Overspray	1	25.00	2	20.00	3	42.86	1	25.00	1	33.33	4	66.67	2	66.67	20	62.5
Cratering	2	50.00	2	20.00	3	42.86	3	75.00	1	33.33	2	66.67	1	33.33	14	43.75
Run/Sags	-	-	-	-	1		1		-	-	1		-	-	3	0.09
Orange-Peel	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	0.03

Table 3.3 Defective Rate per Type/Month

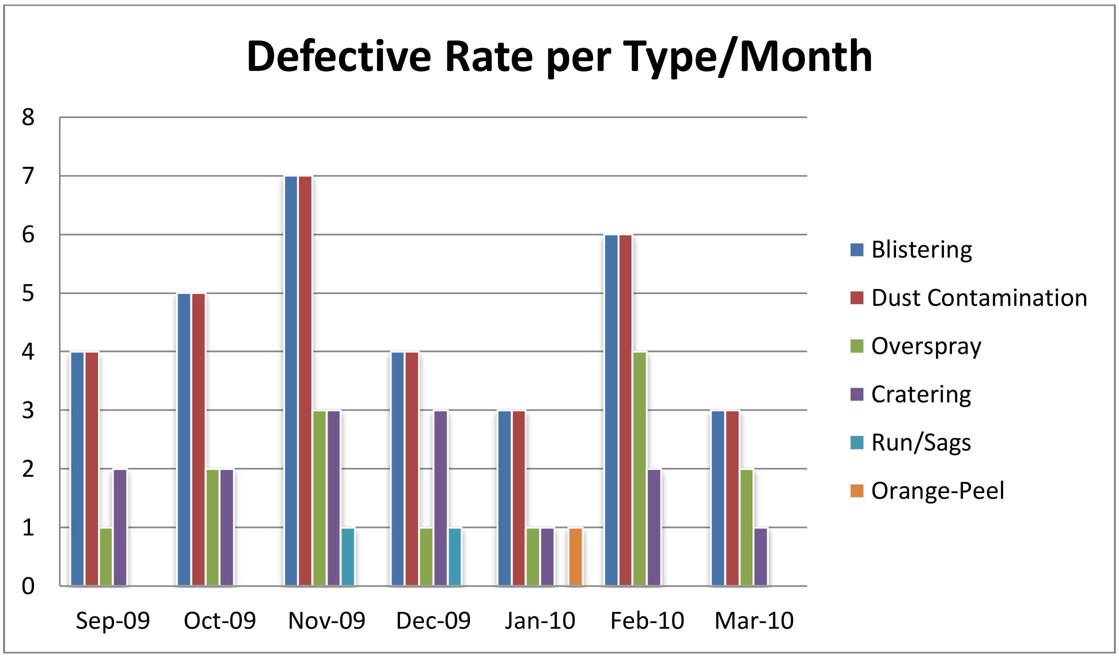
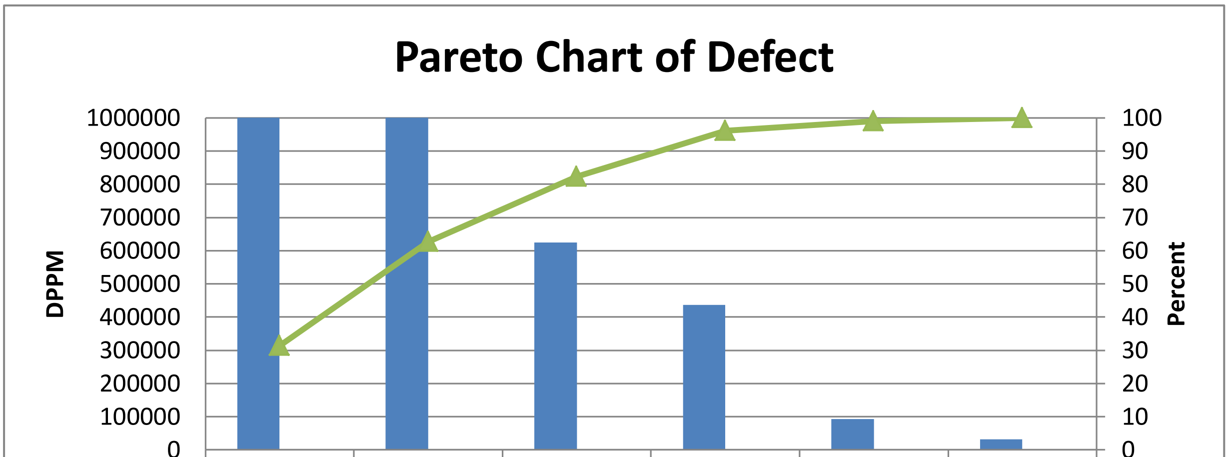


Figure 3.5 Defective Rates per Type/Month Graph

3.3.1 Stage of problem

The study objective is to reduce the waste in vintage car painting. From the figure 3.6, the highest major causes of the defects from spray painting are blistering/solvent boil and dust Contamination.



	Blistering	Dust Contamination	Overspray	Cratering	Run/Sags	Orange-Peel
DPPM	1000000	1000000	625000	437500	93750	31250
Percent	31.37	31.37	19.61	13.73	2.94	0.98
Cum %	31.37	62.74	82.35	96.07	99.01	100

Figure 3.6 Pareto Chart of Defect

The researcher visions that the study of reducing the waste from blistering/solvent boil and dust contamination will be greatly beneficial to quality improvement of the products.

For high accurate result, the blistering/solvent boil and dust contamination defects from the spray painting process from painted cars in May 2010 are collected by measure painting area in to multiple square grids that size 10cm*10cm each. Then the grid that has at least one blistering/solvent boil or dust contamination is defined to be a defect piece. The defective rate of blistering/solvent boil in term of 10cm*10cm grid is show in table 3.4.

	May 2010 (500 PCS)	
	PCS	%
Blistering/Solvent Boil	169	33.8
Dust Contamination	351	70.16

Table 3.4 Blistering/Solvent Boil and Dust Contamination Defect rate in May 2010

3.3.2 Characteristic of Blistering/Solvent boil in Vintage car Painting

From the study about the blistering/solvent boil problem, we can divide the problem into 2 types as follows:

1. The water vapour, oil vapour, or solvent constrained inner the film inflate and make the film to protrude a small spot with needle top size.
2. The water vapour, oil vapour, or solvent constrained inner the film inflate between the film and atmosphere, then it cannot evaporate before the film dried. This cause the small hole spot with needle top size.

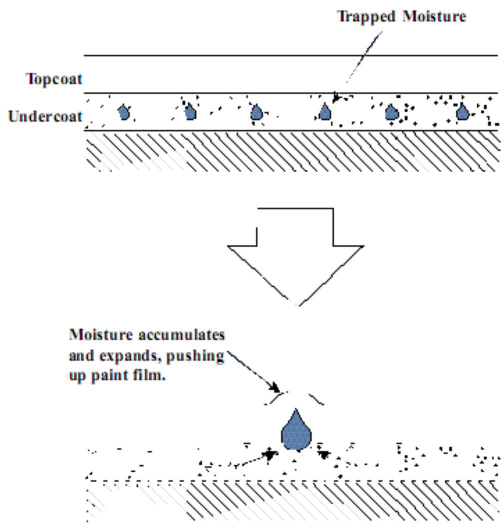


Figure 3.7 Blistering/Solvent Boil [15]

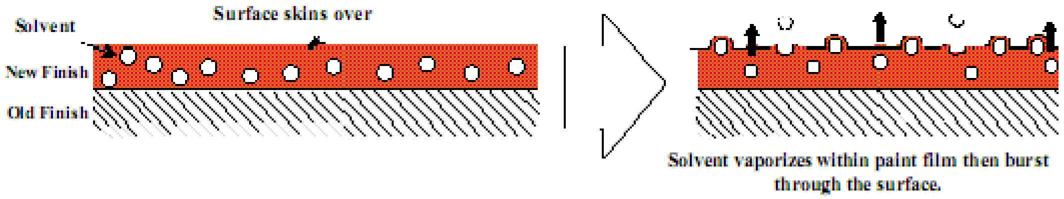


Figure 3.8 Blistering/Solvent Boil [15]

3.3.3 Blistering/Solvent boil Inspection procedure

Step 1. Stand away from the painted part with the lamp in hand far away from the colour surface about 50 cm. and look with 60 degree refer to the surface.

Step 2. Verify the painted part by touching with bear hand lightly.

Step 3. Verify with eyesight from the position parallel to the workings surface.

Step 4. Verify the distortion of reflex of lamp on the workings surface.

Step 5. Verify by using the nail lightly rake the point which is considered to be blistering/solvent boil point.

3.3.4 Characteristic of Dust Contamination in Vintage car Painting

From the study of dust contamination issue, there are 2 types as follows:

1. The dust grain immerses to the surface of under layer coat or immerse deep though the surface of under layer coat.

2. The dust grain immerse not thicker than the coat which is spraying. The solution for each issue is different as mentioned earlier.

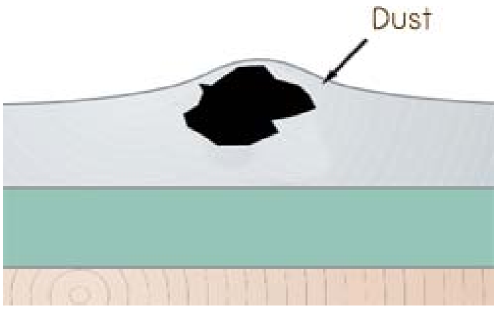


Figure 3.9 Dust Contamination in only top layer coat

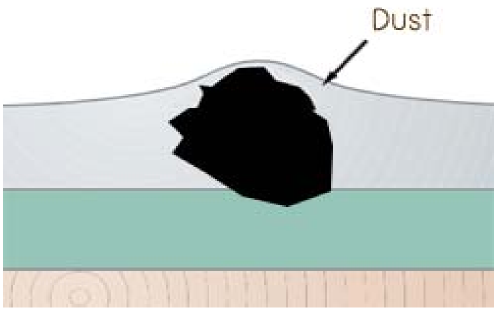


Figure 3.10 Dust Contamination in top layer and under layer coat

3.3.5 Dust contamination Inspection procedure

Step 1. Stand away from the painted part with the lamp in hand far away from the colour surface about 50 cm. and look with 60 degree refer to the surface.

Step 2. Verify the painted part by touching with bear hand lightly.

Step 3. Verify with eyesight from the position parallel to the workings surface.

Step 4. Verify the distortion of reflex of lamp on the workings surface.

Step 5. Verify by using the nail lightly rake the point which is considered to be dust contamination point.

3.4 Conclusion

From the brainstorming of the team in defining the problem step and from the information gathering step from September 2009 to March 2010, we have found that spray painting of the vintage car has several defects. The main causes analysed from Pareto chart are blistering/solvent boil and dust contamination. Thus, our objective is improving the spray painting process to reduce the defects happened.

CHAPTER IV

CAUSE OF THE PROBLEM

Measurement system is very important. Measurement is like the quality control mechanism for the products and quality assurance before delivery to the customer. Measurement process has several major components as follows:

1. Measurement tool
2. Measurement appraiser which is the result from skill, expertise, and training level
3. Measurement method
4. Environment which is the result from temperature, moisture and nature

The different components result in the variance in the measurement system.

Analysis of accuracy system of measurement tools is very important since we need to assure the stability of measurement tools for solving the quality problem or preventing the problem effectively. The objective of accuracy system analysis is to analyse an error of measurement system in production process if it could be acceptable or not. Statistic of characteristic of measurement system analysis divided variance source into part-to-part variation, appraiser variation, and interaction variation.

In this step, the team members will measure to study the source which is the cause of problem by using the statistic tool in the study. Furthermore, they will analysis the accuracy of measurement system in spray painting process to assure the correctness of data from the measurement before doing the experimentation for analysis of problem to select the factors for further study that is selected by Cause and Effect Diagram, Pareto Diagram, GR&R (Gage Repeatability and Reproducibility)and FMEA(Failure Mode and Effect Analysis)

4.1 GR&R Analysis

In the research, the variables we study are dust contamination and blistering/solvent boil problems appeared on the workings. It is the variable that has attribute characteristic such as passed or not passed which is the data obtained from counting or attribute date. Thus, the measurement system analysis is necessary to analyse the accuracy of the measurement system.

4.1.1 Design of GR&R Analysis

1. Bring 2 verification workers who have passed the training since this process check the quality of workings by only 2 persons which are painter and supervisor. Each verification staff is the expert and has great experience in quality check.

2. Make the sample parts by spray painting with the same process as the real workings on steel plate with dimension 20*20 cm for 20 pieces. Do the spray painting with good result for 10 pieces and bad result for 10 pieces with much defect and small defect.

3. Do the experiment as verification plan in table 4.1 which the workers will be completely randomized design. Each worker will verify the parts 2 times.

4. Record the experiment result in the record form.

5. Analyze and summarize the measurement of data analysis with various indexes.

$$\%\,Repeatability\ of\ workers = \frac{The\ number\ of\ the\ same\ verification}{the\ number\ of\ workings} \times 100$$

$$\%\,Reproducibility\ of\ workers = \frac{The\ number\ the\ both\ workers\ have\ the\ same\ result}{the\ number\ of\ workings} \times 100$$

$$Effectiveness\ of\ Repeatability\ of\ Verification = \frac{The\ number\ of\ the\ same\ verification\ and\ correct}{the\ number\ of\ workings\ verified}$$

$$\%\ \text{Effectiveness of Reproducibility of Verification} = \frac{\text{The number the both workers verify correctly}}{\text{the number of workings verified}} \times 100$$

4.1.2 Acceptance Criterion

The acceptance criterion of the measurement system with bare eyes according to the company verification system standard is that the %Repeatability of workers, %Reproducibility of workers, Effectiveness of Repeatability of Verification and %Effectiveness of Reproducibility of verification must be 100%

.

Sample	Sample Quality	Worker A		Worker B	
		1st	2nd	1st	2nd
1	ND	ND	ND	ND	ND
2	D	D	D	D	D
3	ND	ND	ND	ND	ND
4	D	D	D	D	D
5	ND	ND	ND	ND	ND
6	D	D	D	D	D
7	ND	ND	ND	ND	ND
8	D	D	D	D	D
9	ND	ND	ND	ND	ND
10	D	D	D	D	D
11	ND	ND	ND	ND	ND
12	D	D	D	D	D
13	ND	ND	ND	ND	ND
14	D	D	D	D	D
15	ND	ND	ND	ND	ND
16	D	D	D	D	D
17	ND	ND	ND	ND	ND
18	D	D	D	D	D
19	ND	ND	ND	ND	ND
20	D	D	D	D	D

Table 4.1 Measuring data (D = Defect Part, ND = Non Defect Part)

From the above data in table 4.1, an evaluation of repeatability of each worker will consider from the same capability of verification without the correctness of verification.

% Repeatability of worker A = 100%

% Repeatability of worker B = 100%

An evaluation of % Reproducibility of each worker will consider from the same result and correctness.

% Reproducibility of Verification of worker A = 100%

% Reproducibility of Verification of worker B = 100%

The result of evaluation found that each worker has very good repeatability and reproducibility. Thus, the result from workings inspection is trustworthy.

Effectiveness evaluation of overall checking system includes Effectiveness of repeatability and % reproducibility of the verification is evaluated by considering the workers can verify repeatedly and correctly according with the physical workings quality.

Effectiveness of Repeatability of Verification of worker A = 100%

Effectiveness of Repeatability of Verification of worker B = 100%

The test results have found that measuring capability of 2 workers is effective in both repeatability and reproducibility aspect excellently. Thus, the data obtained from this counting is trustworthy and can be used for the next step.

4.2 Cause and Effect Diagram

Cause and Effect Diagram will be used as the tool for brainstorming from the team members that are expert and have experience in car spray painting to obtain the cause of the problems and prove the fact for solving the problem and improvement. The procedures to identify the most possible cause of problem by brainstorming of the team members are as follows:

1. Study the topcoat painting process deliberately by visiting the painting site and studying from the recorded data.
2. After study the recorded data, organize the meeting to specify all possible factors that cause the flaw from the spray painting by applying cause and

effect diagram. The brainstorming is independent to obtain many possible results as much as possible. All factors of blistering/solvent boil are indicated in the figure 4.1 and the factors of dust contamination problem are indicated in figure 4.2

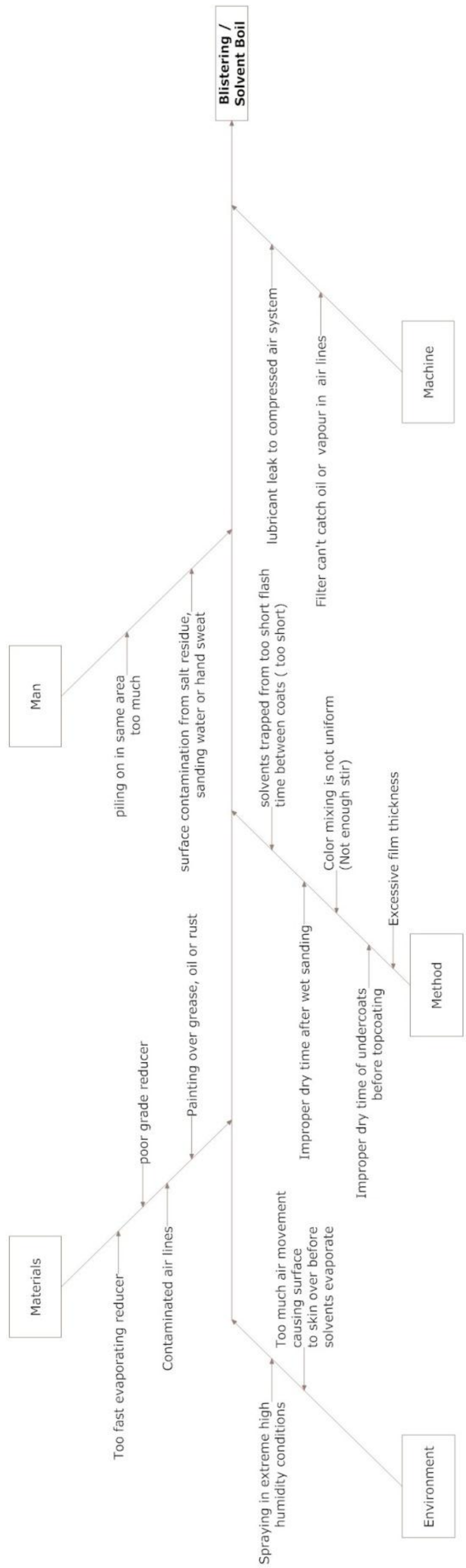


Figure 4.1 Cause and Effect Diagram of Blistering

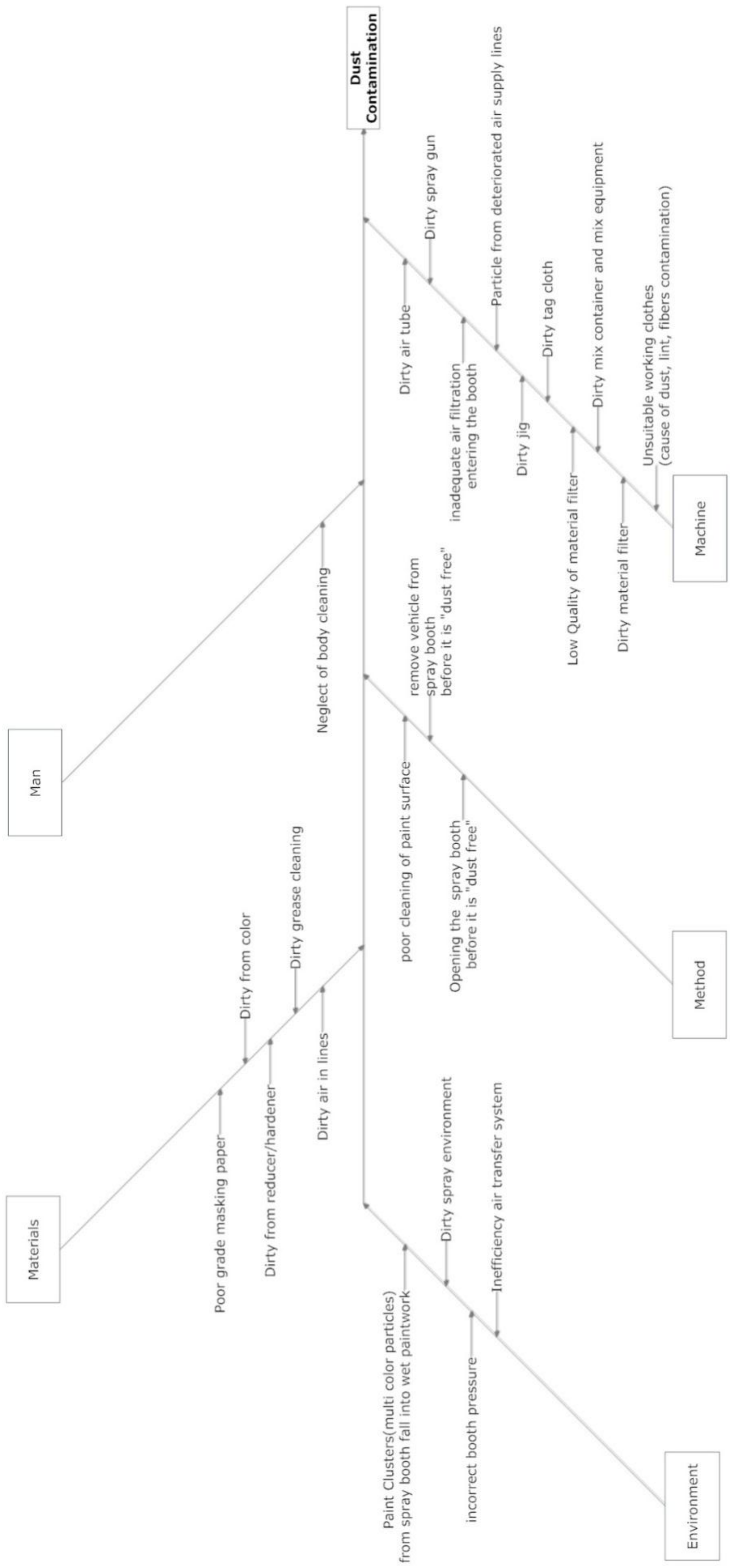


Figure 4.2 Cause and Effect Diagram of Dust Contamination

4.3 Cause and Effect Matrix

From the cause analysis of blistering/solvent boil and dust contamination in spray painting, indicates that there are many causes. Hence, we need to discover the main factor that results in the problem by scoring the cause and effect relationship of the problem. (C-E Matrix) This can be able to select only the factors related to respondent variable which has an effect on the occurrence of blistering/solvent boil and dust contamination problems which can be conducted as follows:

1. Use the data from cause and effect diagram obtained from brainstorming to fill in cause and effect matrix table with defining the importance as the table 4.2

Cause and Effect Relation Level	Score
1. High: Input factor directly affect and highly relate to cause of the problem.	5
2. Mid: Input factor moderately affect and moderately relate to cause of the problem.	3
3. Low: Input factor slightly affect and slightly relate to cause of the problem.	1
4. No Relation: Input factor does not affect and relate to cause of the problem.	0

Table 4.2 Rule of Cause and Effect Diagram Scoring

2. The team member will ballot the point of importance referred to the criterion from table 4.3 and 4.4 which the scores will be in range 0 to 5 point. Define the ratio from effect of the factors that relate to the problems. Each person will ballot all factors in the form.
3. Collect all point in each factor and summary the score result in the cause and effect matrix table. Grade the importance of each factor by sorting with Pareto chart in descending order.

Cause and Effect Matrix of blistering/solvent Boil is showed as follow.

Factors	No.	Key Process Inputs Variables (KPIV)	Score
Machine	1	Lubricant leak to compressed air system	9
	2	Contaminated air lines	15
Man	3	Piling on in same area too much	14
	4	Surface contamination from salt residue, sanding water or hand sweat	10
Method	5	Solvents trapped from too short flash time between coats (too short)	14
	6	Improper dry time after wet sanding	4
	7	Colour mixing is not uniform	13
	8	Improper dry time of undercoats before top coating	9
	9	Excessive film thickness	15
Materials	10	Too fast evaporating reducer	15
	11	Poor grade reducer	4
	12	Filter can't catch oil or vapour in air lines (inefficient filtration)	20
	13	Painting over grease, oil or rust	17
Environment	14	Spraying in extreme high humidity conditions	6
	15	Too much air movement causing surface to skin over before solvents evaporate	2

Table 4.3 Cause and Effect Matrix of Blistering/Solvent Boil

Then, build the Pareto chart in figure 4.3 from the total value to select the vital factors that cause blistering/solvent boil to do Failure Mode & Effects Analysis in coming step.

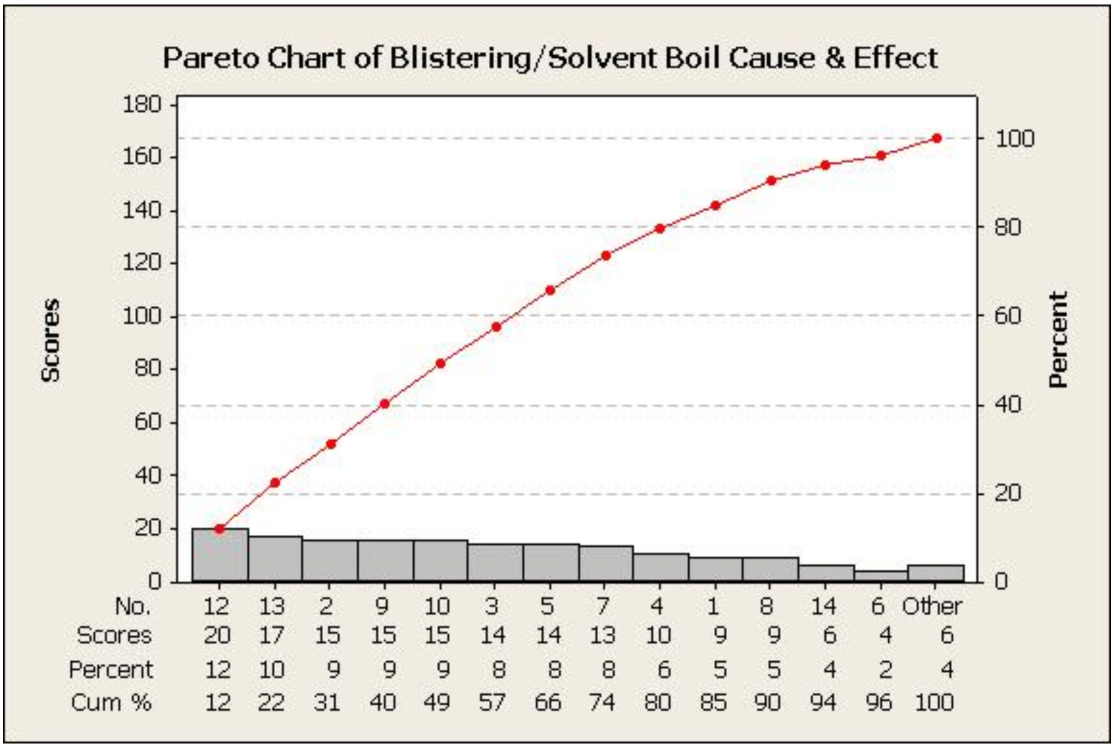


Figure 4.3 Pareto Chart of Blistering/Solvent Boil Cause & Effect matrix

From Pareto chart from cause and effect matrix of blistering/Solvent boil in figure 4.3, factors that critical to the defect are listed below

1. Contaminated air lines
2. Painting over grease, oil or rust
3. Filter can't catch oil or vapour in air lines (inefficient filtration)
4. Excessive film thickness
5. Too fast evaporating reducer
6. Pilling on in same area too much
7. Solvents trapped from too short flash time between coats
8. Colour mixing is not uniform
9. Surface contamination from salt residue, sanding water or hand sweat

Total percentage of nine KPIVs is 79.64% of all KPIVs.

Cause and Effect Matrix of dust contamination is showed in table 4.4

Factors	No.	Key process Input Variables(KPIV)	Score
Machine	1	Dirty air tube	4
	2	Dirty spray gun	20
	3	Inadequate air filtration entering the booth	4
	4	Particle from deteriorated air supply lines	1
	5	Dirty jig	15
	6	Dirty tag cloth	3
	7	Low quality of material filter	3
	8	Dirty mixing container and mixing equipment	10
	9	Dirty material filter	13
Man	10	Unsuitable working clothes(cause from dust, lint, fibres contamination	19
	11	Neglect of body cleaning	17
Method	12	Poor cleaning of paint surface	9
	13	Remove car from spray booth before it is “dust free”	0
	14	Opening or un-air lock the spray booth before it is “dust free”	7
Materials	15	Poor grade masking paper	15
	16	Dirty from colour	4
	17	Dirty from reducer/hardener	7
	18	Dirty grease cleaning	6
	19	Dirty air in lines	15
Environment	20	Paint clusters (multi-colour particles) from spray booth fall into wet paintwork	10
	21	Dirty painting environment	20
	22	Incorrect booth pressure	1
	23	Inefficiency air transfer system	5

Table 4.4 Cause and Effect Matrix of dust contamination

Pareto chart of Dust Contamination cause and effect matrix is shown in figure 4.4

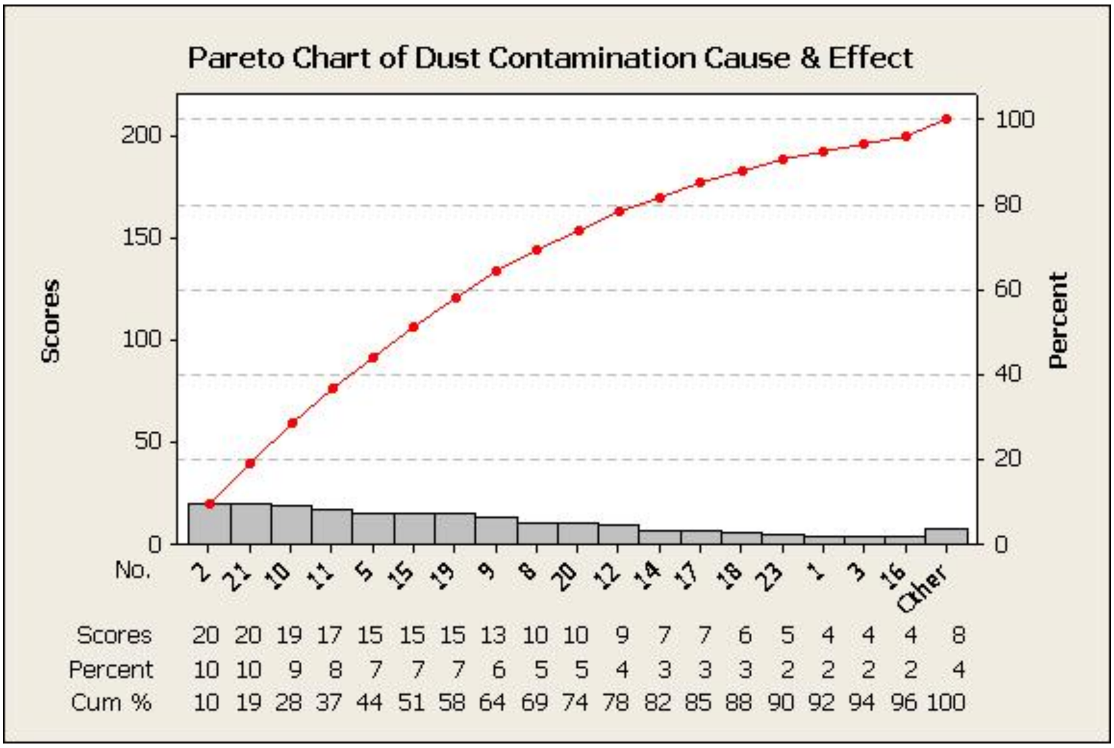


Figure 4.4. Pareto Chart of Dust Contamination Cause & Effect matrix

From Pareto chart from cause and effect matrix of dust contamination in figure 4.4, factors that critical to the defect are listed below

1. Dirty spray gun
2. Dirty painting environment
3. Unsuitable working clothes (from of dust, lint, fibres contamination)
4. Neglect of body cleaning
5. Dirty jig
6. Poor grade masking paper
7. Dirty air in lines
8. Dirty material filter
9. Dirty mixing container and mixing equipment
10. Paint clusters (multi-colour particles) from spray booth fall into wet paintwork
11. Poor cleaning of paint surface

Total percentage of nine KPIVs is 79.64% of all KPIVs.

4.4 Failure Mode and Effects Analysis (FMEA)

After consideration and selection the important factors related to dust contamination and blistering/solvent boil in painting process with the Pareto chart, we will use the selected factors to analyse failure characteristic and effects by using FMEA tool to study characteristic of the problem caused by these factors and consider about the effects as well.

In this process, team members, included manager, body & painting department supervisor and painter is guided the FMEA procedure and emphasized on the meaning of scoring and the meaning of each score level to guarantee that team members will assign the scores efficiently as following instruction.

Failure Modes and Effects Analysis procedure

1. Identify the details of process step. Split the interesting step into minor steps by specifies the process detail included the use that may have an effect on the problems.
2. Identify the Key Process Input.
3. Determine the Potential Failure Mode. If the operations in each step are not aligning to the plan, what will the failure mode be?
4. Determine the effects of the failure mode that tend to happen. How the effects have an effect on the workings.
5. Determine the Severity of the effects to the problems.
6. Determine the Potential Causes of the problems.
7. Determine the Occurrence of the problems.
8. Determine the current process control to prevent the failure modes that are possible to happen.
9. Determine the Detection or estimate the possibility to discover the problems.
10. Calculate Risk Priority Number (RPN)

Calculate the importance of risk value (RPN from the multiple of 3 parameters which are O*S*D)

S = Severity is the hazard of the effects when the problems happened. The standard of the scoring if 1 – 10 while 1 is the lowest level of effects when the problems happened and 10 is the highest level of the effects when the problems happened. The criterion of scoring is regulated by table 4.5.

Severity Level	severity	Score
Very High	Highly affect to the production. All of the paint part(75%-100%) may have to rework	9-10
High	Rather highly affect to the production. Most of the paint part (50% - 75%) may have to rework. The rest of them may have to be sanding to remove defect	7-8
Moderate	Moderately affect to the production. Most of the paint part (25% - 50%) may have to rework. The rest of them may have to be sanding to remove defect	5-6
Low	Rather low affect to the production. Most of the paint part (1% - 25%) may have to rework. The rest of them may have to be sanding to remove defect	3-4
Very Low	Very low affect to the production. All of the painted part may have to be sanding to remove defect	1-2

Table 4.5 Severity Table

O = Occurrence is the frequency of the occurrences, failures or erroneousness of the problems. The standard of the scoring if 1 – 10 while 1 is the least frequency of the occurrences, failures or erroneousness of the problems and 10 is the most frequency of the occurrences, failures or erroneousness of the problems.

Occurrence Level	Rate of Occurrence	Score
Very high	More than 50%	9-10
High	25% - 50%	7-8
Moderate	10% - 25%	5-6
Low	1% - 10%	3-4
Very Low	0.1-1%	1-2

Table 4.6 Occurrence Table

D = Detecting is the capability to detect the problems before delivery the workings or products to the customers.

Detecting Level	Defecting	Score
Almost unable to detect	Doesn't have the knowledge or method to detect the defects	9-10
Difficult to detect	Low occasion that control system will defect the defects	7-8
Moderately to detect	Moderate occasion that control system will defect the defects	5-6
Easy to detect	high occasion that control system will defect the defects	3-4
Almost 100% detectable	Almost defect can be detected by control system	1-2

Table 4.7 Detection table

The result of Failure Mode and Effects Analysis of blistering/solvent boil is shown in table 4.8

Failure Mode and Effect Analysis of Blistering/Solvent Boil defective									
Process Name: Painting **Project Team:** Team Chief, Manager, Body&Painting department supervisor, Painter									
Process (Step)	Key Process Input	Potential Failure Mode (process defects)	Potential Effect of Failure	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN
1	Contaminated air lines	Vapour drop on painting surface	Blistering/Solvent Boil defect on painting part	5	Low maintainance equipment such as air pipe, valve	3	Maintainace and replace by follow instruction	7	105
2	Painting over grease, oil or rust	Blistering/Solvent Boil from grease, oil rust under painting film	Blistering/Solvent Boil defect on painting part	9	Painter doesn't follow cleaning instruction	3	Cleaning painting surface by follow instruction	3	81
3	Filter can't catch oil or vapour in air lines	Oil or vapour drop on painting surface	Blistering/Solvent Boil defect on painting part	7	ineiificiancy compressed air generated system	10	pufiry air lines by vapour,oil seperation	7	490
4	Excessive film thickness	Solvent bubble traped under painting film	Blistering/Solvent Boil defect on painting part	4	Painter doesn't follow painting instruction	9	Paint by follow painting instruction	5	180
5	Excessive film thickness	Solvent push up to painting surface	Blistering/Solvent Boil defect on painting part	8	Type of reducer doesn't match with painging condition	8	Mixing color by follow mixing instruction	4	256

Failure Mode and Effect Analysis of Blistering/Solvent Boil defective

Process Name: Painting

Project Team: Team Chief, Manager, Body&Painting department supervisor, Painter

Process (Step)	Key Process Input	Potential Failure Mode (process defects)	Potential Effect of Failure	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN
6	Pilling on in same area too much	Solvent can't left painting film	Blistering/Solvent Boil defect on painting part	3	Some area of painting surface are painted too much	4	Paint by follow painting instruction	3	36
7	Solvents trapped from too short flash time between coats (too short)	Solvent trapped from upper coating	Blistering/Solvent Boil defect on painting part	6	Painting doesn't follow instruction strickly	3	Paint by follow painting instruction	3	54
8	Color mixing is not uniform	Solvent trapped under the paint surface	Blistering/Solvent Boil defect on painting part	5	Color isn't stir enough	7	Checking color uniform by eye	8	280
9	Surface contamination from salt residue, sanding water or hand sweat	Blistering/Solvent Boil from grease, oil rust under painting film	Blistering/Solvent Boil defect on painting part	8	Painting part doesn't clean enough before painting	3	Cleaning by follow cleaning instruction	3	72

Pareto chart of FMEA of Blistering/Solvent boil is shown in figure 4.5.

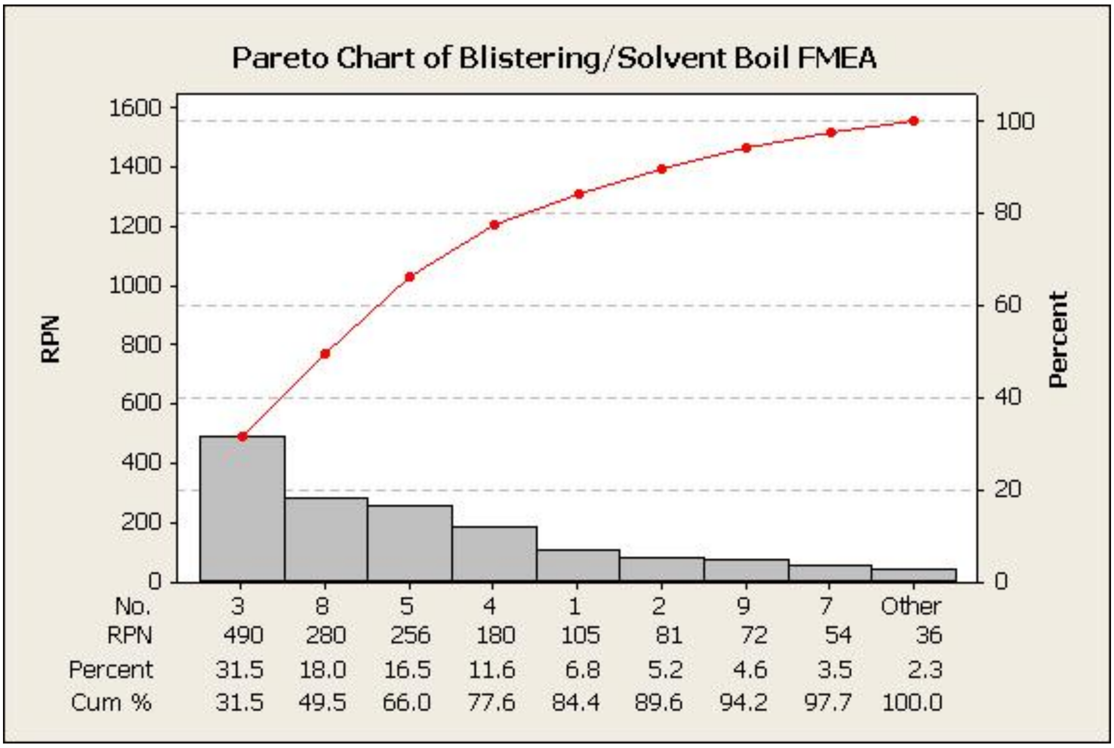


Figure 4.5. Pareto Chart of Blistering/Solvent Boil FMEA

From Pareto chart from FMEA of blistering/Solvent boil in figure 4.5, key process input variables that critical to the defect are listed below.

1. Filter can't catch oil or vapour in air lines (inefficient filtration)
2. Colour mixing is not uniform
3. Too fast evaporating reducer
4. Excessive film thickness

The result of Failure Mode and Effects Analysis of dust contamination is shown in table 4.9

Failure Mode and Effect Analysis of Dust Contamination Defective

Process Name : Painting

Project Team: Team Chief, Manager, 3. Body&Painting department supervisor, Painter

Process (Step)	Key Process Input	Potential Failure Mode (process defects)	Potential Effect of Failure	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN
1	Dirty spray gun	Dust in painting booth from spray gun	Dust Contamination defect on painting part	8	unsuitable cleaning method and schedule	7	Cleaning by schedule	5	280
2	Dirty painting environment	spreaded Dust in painting booth	Dust Contamination defect on painting part	7	unsuitable cleaning method and schedule	8	Cleaning by schedule	5	280
3	Unsuitable working clothes(cause from of dust, lint, fibers contamination)	Dust in painting booth from clothes	Dust Contamination defect on painting part	5	unsuitable cloth for painting job	7	pufiry air lines by vapour,oil seperation	9	315
4	Neglect of body cleaning	Dust in painting booth from non cleaned body	Dust Contamination defect on painting part	7	Painter doesn't follow the instruction	8	Cleaning by follow painting instruction	4	224
5	Dirty jig	Dust in painting booth from jigs	Dust Contamination defect on painting part	5	unsuitable cleaning method and schedule	3	Mixing color by follow mixing instruction	4	60

Failure Mode and Effect Analysis of Dust Contamination Defective

Process Name : Painting

Project Team: Team Chief, Manager, 3. Body&Painting department supervisor, Painter

Process (Step)	Key Process Input	Potential Failure Mode (process defects)	Potential Effect of Failure	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN
6	Poor grade masking paper	Dust in painting booth from masking paper	Dust Contamination defect on painting part	5	unsuitable masking paper for painting job	7	masking by clean recycle paper	9	315
7	Dirty air in lines	Dust from air that distribute to spray gun	Dust Contamination defect on painting part	6	low efficiency particle filter	3	eliminate particle in air by filter	3	54
8	Dirty material filter	Dust in color from material filter	Dust Contamination defect on painting part	7	Painter doesn't follow the instruction	5	Cleaning by follow instruction	3	105
9	Dirty mixing container and mixing equipment	Dust in color from equipment	Dust Contamination defect on painting part	7	Painter doesn't follow the instruction	5	Cleaning by follow instruction	3	105
10	Paint clusters (multi-color particles) from spray booth fall into wet paintwork	paint particles in painting booth that is left over from previous painting job	Dust Contamination defect on painting part	9	unsuitable cleaning method and schedule	2	Cleaning by schedule	3	54
11	Poor cleaning of paint surface	Dust doesn't clean off the surface before painting	Dust Contamination defect on painting part	8	Painter doesn't follow the instruction	1	Painted surface cleaning by follow instruction	3	24

Pareto chart of FMEA of dust contamination is shown in figure 4.6

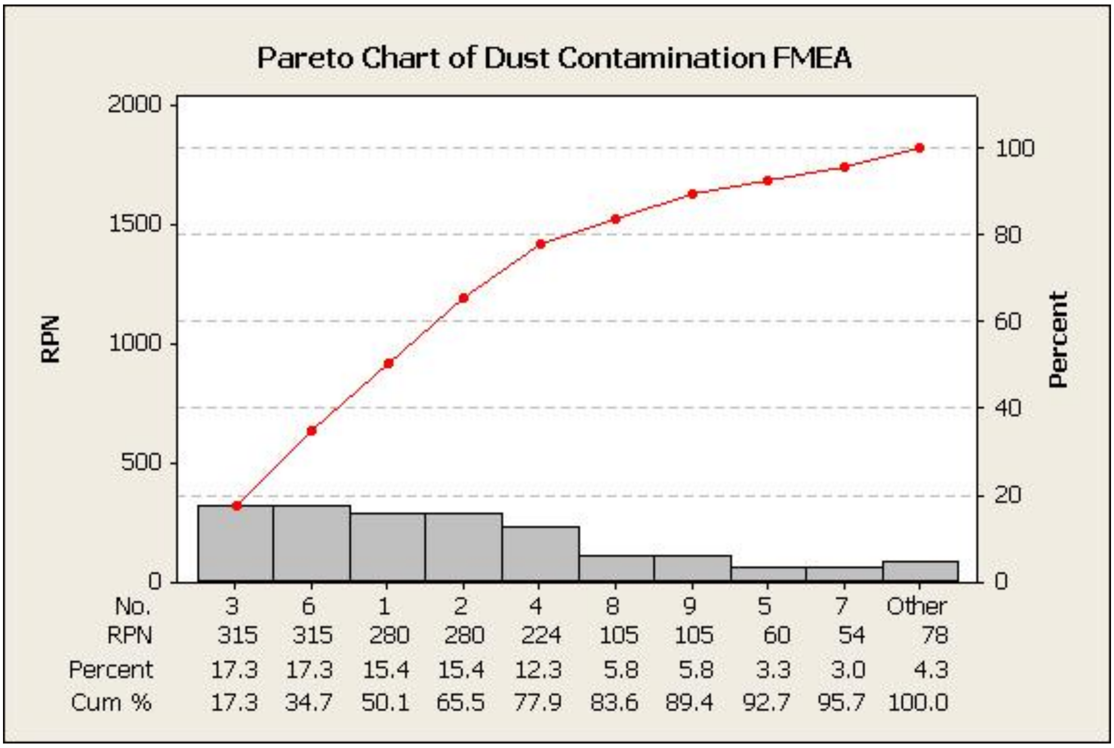


Figure 4.6. Pareto Chart of Dust Contamination FMEA

From Pareto chart from FMEA of dust contamination in figure 4-6, key process input variables that critical to the defect are listed below.

1. Unsuitable working clothes (cause from dust, lint, fibres contamination)
2. Poor grade masking paper
3. Dirty spray gun
4. Dirty painting environment
5. Neglect of body cleaning

CHAPTER V

THE EXPERIMENTS

After the determination of the problems, this chapter will describe about cause analysis of blistering/solvent boil and dust contamination problems in vintage car topcoat painting. The analysis will be in statistical aspects consist of the major steps which are formulation of hypothesis and testing the hypothesis. The analysis will analyse the sorted causes which have an effect on happening of the waste mentioned in the last chapter. This procedure will analyse one factor at a time which is easy to analyses. However, it cannot test the Interaction effect between the factors. Thus, the engineering knowledge, understanding and experience in studying process are needed in the analysis to determine which factors are independent and which factors are likely to have an effect on other factors for the correctness in analysis and accuracy of the result.

Analysis and elimination of the causes of the problems will analyse one factor at a time. There are possibilities that the failures will be eliminated or get better to the satisfactory state. Thus, the analysis to identify the causes of the problems must do the experiment and collect the data to confirm that these causes are the factors that have an effect on the quality problems.

5.1 Hypothesis tests from Key Processes Input

From Previous chapter, factors that highly affect to blistering/solvent boil defect are listed below.

1. Filter can’t catch oil or vapour in air lines (inefficient filtration)
2. Colour mixing is not uniform
3. Too fast evaporating reducer
4. Excessive film thickness

From Previous chapter, factors that highly affect to dust contamination defect are listed below.

1. Unsuitable working clothes (cause from dust, lint, fibres contamination)

2. Poor grade masking paper
3. Dirty spray gun
4. Dirty painting environment
5. Neglect of body cleaning

The following tests are focused on factors of blistering/solvent boil and dust contamination defective. The tests are performed on 4 pieces of prepared for topcoat metal sheets that is the same as car surface. Each sheet is divided in to 4 pieces of test unit that size 10cm*10cm with accuracy +/- 1mm. The response is amount of defective piece. In this section the one factor at a time (OFAT) technique is employed to confirm the significant impact of these variables to the blistering/solvent boil defect.

The two-proportion test is applied to test for significant impact of the variables to the response. The level of setting throughout the experiment is as below

Level of confidence = 95%

Level of significance (α) = 0.05

Hypothesis Testing is to test the difference in two proportions between two variables. The null hypothesis is the proportions of two variables are not different and the alternative hypothesis is the proportions of two variables are different. The mathematic signs are showed below

$$H_o \ : \ p_1 - p_2 = 0$$
$$H_a \ : \ p_1 - p_2 \neq 0$$

Decision Making: If the p-value is larger than commonly chosen α level, the data are consistent with the null hypothesis. If the p-value is lesser than α level, the data are consistent with the alternative hypothesis.

5.2 Hypothesis tests of Blistering/Solvent Boil

The present blistering/Solvent Boil defect yields at 33.8% while the target result of defect reduction project is 8.45%. To be precise, the power of test is set at 90%. By Minitab calculating, the required sample size is 53 pieces. In order to reduce cost and time of experiment, the team agrees to reduce the sample size to 16 pieces.

Power and Sample Size

```
Test for Two Proportions

Testing comparison p = baseline p (versus not =)
Calculating power for baseline p = 0.0845
Alpha = 0.05


                  Sample  Target
Comparison p        Size   Power  Actual Power
       0.338          53     0.9      0.903420

The sample size is for each group.
```

Power Curve for Two Proportions

Figure 5.1 Sample Size of Blistering/Solvent Boil two-proportion test

5.2.1. Filter can’t catch oil or vapour in air lines (inefficient filtration)

Oil and Vapour in compressed air system is one of cause of the defect in painting process. In spray painting, compressed air is using as a medium to deliver colour pigment to painted surface. Then oil and vapour is deliver to the surface and turn to the defect as well, if purify system can’t percolate them efficiently. Air dryer in this test is shown in figure 5.2

Figure 5.2 Pneudri Midus Air Dryer

The following is the test of difference of proportions between painting with air dryer and without air dryer system.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted with air dryer system and parts that will be painted without air dryer system.

2. Send both groups of parts to painting process that is painted with air dryer and without air dryer, respectively

3. Inspect the blistering/solvent boil defect on each piece and record the results.

Hypothesis

$$H_o : p_1 - p_2 = 0$$
$$H_a : p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the blistering/solvent boil defect when painting with air dryer system and parts that painting without air dryer system, respectively.

Result Interpretation

From the test and calculation in figure 5.3, the p-value 0.007 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of blistering/solvent boil by painting with air dryer system is different from that of painting without air dryer system with 95% confidence.

Test and CI for Two Proportions

```
Sample   X   N  Sample p
1       16  16  1.000000
2       11  16  0.687500


Difference = p (1) - p (2)
Estimate for difference:  0.3125
95% CI for difference:  (0.0853831, 0.539617)
Test for difference = 0 (vs not = 0):  Z = 2.70  P-Value = 0.007
```

Figure 5.3 Test for two-proportion of painting with air dryer system and painting without air dryer system.

5.2.2. Colour mixing is not uniform

Pure colour has to be mixed with reducer and hardener before spray painting that the not adequate blending cause blistering/solvent boil on painted surface. This test is performed between two blending times. The first blending times come from record of blending time that provide 21 seconds of viscosity cup measuring in DIN4 standard that recommend by colour manufacturer.(BASF Coating GmbH, 2010) The second blending time is recorded average blending time in current painting process as in figure 5.4.

Figure 5.4 Mixing of painting colour

The following is the test of difference of proportions between blending 9 minute and blending 3 minutes.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted by 9 minutes and 3 minutes blending colour.

2. Send both group of parts to painting process that is painted by 9 minutes and 3 minutes blending colour, respectively

3. Inspect the blistering/solvent boil defect on each piece and record the results.

Hypothesis

$$H_o : p_1 - p_2 = 0$$
$$H_a : p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the blistering/solvent boil defect when paint with 8 minutes blended and 3 minutes blended colour, respectively.

Result Interpretation

From the test and calculation in figure 5.5, the p-value 0.021 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of blistering/solvent boil by painting with 9 minutes blended colour is different from that of painting with 3 minutes blended colour.

Test and CI for Two Proportions

```
Sample    X   N  Sample p
1        15  16  0.937500
2        10  16  0.625000


Difference = p (1) - p (2)
Estimate for difference:  0.3125
95% CI for difference:  (0.0472846, 0.577715)
Test for difference = 0 (vs not = 0):  Z = 2.31  P-Value = 0.021
```

Figure 5.5 Test for two-proportion of painting with 9 minutes blended and 3 minutes blended colour.

5.2.3. Too fast evaporating reducer

The reducers that the colour manufacturer recommend for mixing in spray painting include number 50, 91 and 216 which are fast, medium and slow type respectively. These 3 types of reducers have their own evaporate and dried characteristic in different temperature. Presently, the painting process is using the medium reducer number 91. Researcher team ascribe that using the too fast evaporate reducer will make the particle of the reducer to push the colour film surface and result in defect. The slow reducer number 216 may be more appropriate for the temperature level in painting room.

The following is the test of difference of proportions between mixing with slow reducer and medium reducer.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted with slow reducer and medium reducer mixing formula.

2. Send both group of parts to painting process that is painted with slow reducer and medium reducer mixing formula, respectively

3. Inspect the blistering/solvent boil defect on each piece and record the results.

Hypothesis

$$H_o \ : \ p_1 - p_2 = 0$$
$$H_a \ : \ p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the blistering/solvent boil defect when paint with slow reducer and medium reducer mixing formula, respectively.

Result Interpretation

From the test and calculation in figure 5.6, the p-value 0.021 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of blistering/solvent boil by painting with slow reducer mixing formula is different from that of painting with medium reducer mixing formula with 95% confidence.

Test and CI for Two Proportions

```
Sample   X   N  Sample p
1       16  16  1.000000
2       12  16  0.750000


Difference = p (1) - p (2)
Estimate for difference:  0.25
95% CI for difference:  (0.0378277, 0.462172)
Test for difference = 0 (vs not = 0):  Z = 2.31  P-Value = 0.021
```

Figure 5.6 Test for two-proportion of painting with slow reducer and medium reducer mixing formula.

5.2.4. Excessive film thickness

The drying of the colour film starts from outer part to inner part. Too thick painting makes outside surface set itself the film before the inner reducer will evaporate which is the cause of blistering/solvent boil defect. Presently, the spray painting will paint 3 layers more than the manufacturer advice at 2 layers for the spare thickness in sanding in case of defect occurred. To examine this hypothesis, the researcher has test between 3 layers painting with 80 - 110µm thick measured by thickness gage meter and 2 layers painting with 50 – 70µm as shown in the figure 5.7. In this case, the tool is calibrated its zero value at the total thickness of steel plate included undercoating.

Figure 5.7 Measuring thickness of paint film

The following is the test of difference of proportions between 2 layers painting and 3 layers painting.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted 2 layers and parts that will be painted 3 layers.

2. Send both groups of parts to painting process that is painted 2 layers and parts that painted 3 layers, respectively

3. Inspect the blistering/solvent boil defect on each piece and record the results.

Hypothesis

$$H_o : p_1 - p_2 = 0$$
$$H_a : p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the blistering/solvent boil defect when paint 2 layers and 3 layers, respectively.

Result Interpretation

From the test and calculation in figure 5.8, the p-value 0.276 is greater than 0.05, the null hypothesis is unable to reject at the confidence 95%. That is the proportion of blistering/solvent boil by painting 2 layers may or may not different from that of painting 3 layers.

```
Test and CI for Two Proportions

Sample   X   N  Sample p
1       15  16  0.937500
2       13  16  0.812500


Difference = p (1) - p (2)
Estimate for difference:  0.125
95% CI for difference:  (-0.100043, 0.350043)
Test for difference = 0 (vs not = 0):  Z = 1.09  P-Value = 0.276
```

Figure 5.8 Test for two-proportion of painting 3 layers and 2 layers.

5.3 Hypothesis tests of Dust Contamination

The present dust contamination defect yields at 70.16% while the target result of defect reduction project is 17.54%. To be precise, the power of test is set at 90%. By Minitab calculating, the required sample size is 17 pieces. In order to reduce time of the experiment, the team agrees to reduce the sample size to 16 pieces.

```
Power and Sample Size

Test for Two Proportions

Testing comparison p = baseline p (versus not =)
Calculating power for baseline p = 0.1754
Alpha = 0.05


              Sample  Target
Comparison p    Size   Power  Actual Power
      0.7016      17     0.9      0.909037

The sample size is for each group.
```

Figure 5.9 Sample Size of dust contamination two-proportion test

5.3.1. Unsuitable working clothes (cause from dust, lint, fibres contamination)

Cleanness of paint suit has to determine that it may significant to dust contamination factor. In the hypothesis test, 2 of paint suits, a new cleaned suit and a week used suit is prepared as in figure 5.10. In order to see the result clearly, the position of painter is set in a bend posture parallel to the ground.

The following is the test of difference of proportions between a new cleaned suit and a week used suit.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted with a new cleaned suit and parts that will be painted with a week used suit.

2. Send both groups of parts to painting process that is painted with a new cleaned suit and a week used suit, respectively

3. Inspect the dust contamination defect on each piece and record the results.

Hypothesis

$$H_o \ : \ p_1 - \ p_2 = 0$$
$$H_a \ : \ p_1 - \ p_2 \neq 0$$

Where p_1 and p_2 are proportions of the dust contamination defect when paint with a new cleaned suit and a week used suit, respectively.

Result Interpretation

From the test and calculation in figure 5.10, the p-value 0.049 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of dust contamination by painting with a new cleaned suit is different from that of painting with a week used suit with 95% confidence.

Test and CI for Two Proportions

```
Sample   X   N  Sample p
1       13  16  0.812500
2        8  16  0.500000


Difference = p (1) - p (2)
Estimate for difference:  0.3125
95% CI for difference:  (0.00169591, 0.623304)
Test for difference = 0 (vs not = 0):  Z = 1.97  P-Value = 0.049
```

Figure 5.10 Test for two-proportion of painting with a new cleaned suit and a week used suit.

5.3.2. Poor grade masking paper

In spray painting, masking process is necessary to conceal the area that doesn't want to be paint. In this test, 2 types of masking paper have to determine that it may significant to dust contamination factor. In hypothesis test, 2 kinds of masking from recycle paper and professional masking paper is prepared as in figure 5.11 and figure 5.12, respectively.

Figure 5.11 Masking with recycle paper.

Figure 5.12 Masking with professional masking paper

The following is the test of difference of proportions between masking with professional masking paper and recycle masking paper.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be masked with professional masking paper and parts that will be masked with recycle paper.

2. Send both groups of parts to painting process that is painted by masking with professional masking paper and recycle paper, respectively.

3. Inspect the dust contamination defect on each piece and record the results.

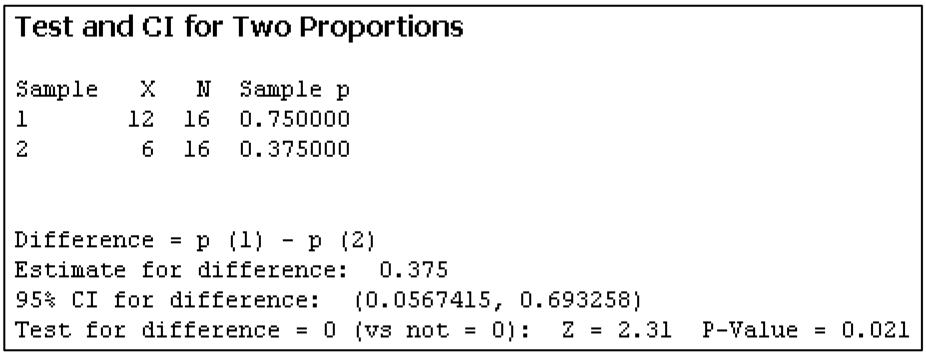
Hypothesis

$$H_o \ : \ p_1 - p_2 = 0$$
$$H_a \ : \ p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the dust contamination defect when paint by masking with professional masking paper and recycle paper, respectively.

Result Interpretation

From the test and calculation in figure 5.13, the p-value 0.021 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of dust contamination by masking with professional masking paper is different from that of masking with recycle paper with 95% confidence.


Test and CI for Two Proportions

Sample	X	N	Sample p
1	12	16	0.750000
2	6	16	0.375000

Difference = p (1) - p (2)
Estimate for difference: 0.375
95% CI for difference: (0.0567415, 0.693258)
Test for difference = 0 (vs not = 0): Z = 2.31 P-Value = 0.021

Figure 5.13 Test for two-proportion of painting by masking

with professional masking paper and recycle paper.

5.3.3. Dirty spray gun

The test is performed by painting on one group of sample with the spray gun used for a day without cleaning and one group with the spray gun that is cleaned before every paint job as in figure 5.14

Figure 5.14 Spray gun Cleaning

The following is the test of difference of proportions between new cleaned spray gun and a day used spray gun.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted by new cleaned spray gun and parts that will be painted by used for a day spray gun.

2. Send both group of parts to painting process that is painted by new cleaned spray gun and parts that will be painted by used for a day spray gun, respectively.

3. Inspect the dust contamination defect on each piece and record the results.

Hypothesis

$$H_o : p_1 - p_2 = 0$$
$$H_a : p_1 - p_2 \neq 0$$

Where p_1 and p_2 are proportions of the dust contamination defect when paint by new cleaned spray gun and used for a day spray gun, respectively.

Result Interpretation

From the test and calculation in figure 5.15, the p-value 0.131 is greater than 0.05, the null hypothesis is unable to reject at the confidence 95%. That is the proportion of dust contamination by painting by new cleaned spray gun may or may not different from that of painting used for a day spray gun.

```
Test and CI for Two Proportions

Sample   X   N  Sample p
1       15  16  0.937500
2       12  16  0.750000


Difference = p (1) - p (2)
Estimate for difference:  0.1875
95% CI for difference:  (-0.0555739, 0.430574)
Test for difference = 0 (vs not = 0):  Z = 1.51  P-Value = 0.131
```

Figure 5.15 Test for two-proportion of painting by new cleaned spray gun and used for a day spray gun.

5.3.4. Dirty painting environment

Painting Environment is one of important factor of dust contamination defective. At the brainstorming state, team found a fine black dust particle in a cleaning cloth when wipe it to the painting booth's wall that isn't cleaned for a month as in figure 5.16. The test is performed by painting on one group of sample in the paint booth that isn't cleaned for a month and one group in the paint booth that isn't cleaned for a week.

Figure 5.16 Dust on painting booth's wall

The following is the test of difference of proportions between painting in the paint booth not cleaned for a week and the paint booth not cleaned for a month.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted in the paint booth not cleaned for a week and parts that will be painted in paint booth not cleaned for a month.

2. Send both groups of parts to painting process that is painted in the paint booth not cleaned for a week and in paint booth not cleaned for a month, respectively

3. Inspect the dust contamination defect on each piece and record the results.

Hypothesis

$$H_o \ : \ p_1 - \ p_2 = 0$$
$$H_a \ : \ p_1 - \ p_2 \neq 0$$

Where p_1 and p_2 are proportions of the dust contamination defect when paint in the paint booth not cleaned for a week and in paint booth not cleaned for a month, respectively.

Result Interpretation

From the test and calculation in figure 5.17, the p-value 0.001 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of dust contamination by painting in the paint booth not cleaned for a week is different from that of painting in paint booth not cleaned for a month with 95% confidence.

Test and CI for Two Proportions

```
Sample   X   N  Sample p
1       13  16  0.812500
2        5  16  0.312500


Difference = p (1) - p (2)
Estimate for difference:  0.5
95% CI for difference:  (0.203085, 0.796915)
Test for difference = 0 (vs not = 0):  Z = 3.30  P-Value = 0.001
```

Figure 5.17 Test for two-proportion of painting in the paint booth not cleaned for a week and in paint booth not cleaned for a month.

5.3.5. Neglect of body cleaning

Before painting, painter has to follow the paint booth rule by self-cleaning by compressed air, neglect of this rule may affect to dust contamination defective as in figure 5.18. The test is performed by painting on one group of sample with painter that clean himself before enter the painting booth and one group with painter that doesn't clean himself before enter the painting booth. In order to see the result clearly, the painting position of painter is set in a bend posture parallel to the ground.

Figure 5.18 Self Cleaning by Compressed air

The following is the test of difference of proportions between self-cleaning and no self-cleaning before enter the painting booth.

The Experiments Method

1. Prepare 2 groups of sample parts, parts that will be painted by self-cleaning painter and parts that will be painted by no self-cleaning painter.

2. Send both groups of parts to painting process that is painted by self-cleaning painter and parts that will be painted by no self-cleaning painter, respectively

3. Inspect the dust contamination defect on each piece and record the results.

Hypothesis

$$H_o \ : \ p_1 - \ p_2 = 0$$
$$H_a \ : \ p_1 - \ p_2 \neq 0$$

Where p_1 and p_2 are proportions of the dust contamination defect when paint by self-cleaning painter and parts that will be painted by no self-cleaning painter, respectively.

Result Interpretation

From the test and calculation in figure 5.19, the p-value 0.012 is lesser than 0.05, the null hypothesis is rejected at the confidence 95%. That is the proportion of dust contamination by painting by self-cleaning painter is different from that of painting by no self-cleaning painter with 95% confidence.

Test and CI for Two Proportions

```
Sample   X   N  Sample p
1       14  16  0.875000
2        8  16  0.500000


Difference = p (1) - p (2)
Estimate for difference:  0.375
95% CI for difference:  (0.0812607, 0.668739)
Test for difference = 0 (vs not = 0):  Z = 2.50  P-Value = 0.012
```

Figure 5.19 Test for two-proportion of painting by self-cleaning painter and no self-cleaning painter.

5.4 Design of Experiment of Blistering/Solvent Boil

Four key process input variables of blistering/solvent boil are the factors that have to be test with DOE (Design of Experiment) to check their interaction between each factor. This section discuss about the type of design, factors and levels to be studied. The result of the experiment is analysed by ANOVA, main effect plot and interaction plot for defining significant factors and their levels.

5.4.1 Factors and Levels

The factors and their levels that are used in the experiment are shown in table 5.1. The levels are set to standard format by assigned the level of each factor to be 1 or -1.

Factors	Level	
	-1	+1
A= Effectiveness of Oil and Vapour Filter	Pass Filter and Air Dryer	Not pass Filter/Air Dryer
B= Thickness of the Paint Film	50-70um	80-110um
C= Mixing Uniform	Blend 3 minute	Blend 9 minute
D= Type of Reducer	Medium (code: 352-50)	Slow (code: 352-216)

Table 5.1 Experiment Factors and levels

5.4.2 Response of the Experiment

The response of the experiment of blistering/solvent boil in painting process is quantity of blistering/solvent boil defect on 20*20cm tested metal sheet with accuracy +/- 1mm.

5.4.3 Type of Design

This experiment is tested by full factorial design that is one of the highest efficiency experiments. The experiment has four factors and one response. Since this experiment has 4 factors, 16 full factorial runs are required to conduct the experiment and team design to run 3 replicates for each factor.

5.4.4 Preparing of the Experiment

The methods to prepare the experiment are described as following.

1. Prepare 48 of 20*20cm prepared for topcoat metal sheets with accuracy +/- 1mm and check that it is suitable to be tested
2. Prepare equipment and material for the experiment
3. Check the control factor.

- Metal sheets come from the same preparation and there is no defect on the sheets.
- Only one set of equipment and material are used in the experiment

- Change some equipment and material to the new ones and checking that there is no any malfunction in any equipment.
- The experiment is tested by same painter

5.4.5 Results of the Experiment

From design of the experiment of 4 factors of blistering/solvent boil defective in painting process that is effectiveness of oil and vapour filter, thickness of paint film, mixing uniform and type of reducer. The experiment is performed in 16 conditions with 3 replicates that Y is the number of defects found in each tested metal sheet. The experiment result is shown in table 5.2

StdOrder	RunOrder	CenterPt	Blocks	A	B	C	D	Y
37	1	1	1	-1	-1	1	-1	2
34	2	1	1	1	-1	-1	-1	3
18	3	1	1	1	-1	-1	-1	2
33	4	1	1	-1	-1	-1	-1	2
11	5	1	1	-1	1	-1	1	1
27	6	1	1	-1	1	-1	1	1
16	7	1	1	1	1	1	1	1
4	8	1	1	1	1	-1	-1	3
10	9	1	1	1	-1	-1	1	1
46	10	1	1	1	-1	1	1	1
31	11	1	1	-1	1	1	1	0
44	12	1	1	1	1	-1	1	2
47	13	1	1	-1	1	1	1	1
45	14	1	1	-1	-1	1	1	0
21	15	1	1	-1	-1	1	-1	1
30	16	1	1	1	-1	1	1	2
24	17	1	1	1	1	1	-1	2
12	18	1	1	1	1	-1	1	4
26	19	1	1	1	-1	-1	1	1
42	20	1	1	1	-1	-1	1	1
39	21	1	1	-1	1	1	-1	1
2	22	1	1	1	-1	-1	-1	2
17	23	1	1	-1	-1	-1	-1	1
36	24	1	1	1	1	-1	-1	2
38	25	1	1	1	-1	1	-1	2
5	26	1	1	-1	-1	1	-1	1
23	27	1	1	-1	1	1	-1	1
9	28	1	1	-1	-1	-1	1	1
1	29	1	1	-1	-1	-1	-1	2
20	30	1	1	1	1	-1	-1	2
25	31	1	1	-1	-1	-1	1	0
48	32	1	1	1	1	1	1	2
32	33	1	1	1	1	1	1	0
13	34	1	1	-1	-1	1	1	0
43	35	1	1	-1	1	-1	1	2
8	36	1	1	1	1	1	-1	1
22	37	1	1	1	-1	1	-1	1
3	38	1	1	-1	1	-1	-1	2
14	39	1	1	1	-1	1	1	0
29	40	1	1	-1	-1	1	1	1
7	41	1	1	-1	1	1	-1	0
6	42	1	1	1	-1	1	-1	3
28	43	1	1	1	1	-1	1	2
15	44	1	1	-1	1	1	1	1
35	45	1	1	-1	1	-1	-1	2
19	46	1	1	-1	1	-1	-1	1
40	47	1	1	1	1	1	-1	2
41	48	1	1	-1	-1	-1	1	0

Table 5.2 The Experiment Result

5.4.6 Residual Analysis

There are three steps to analyse the experiment. The first step is using ANOVA to test the significant factors. The second step is using main effect plot and interaction plot to show which level of factors reduced the response. Third step is testing of assumption of ANOVA by Residual Analysis, before making a conclusion. The three assumptions are listed below.

1. Errors are normally distributed
2. Errors have a constant Variance (σ_e^2)
3. Errors are statistically independent

Before starting the experiment the numbers of defects are necessary to be square-root transformation because the data nature has Poisson distribution.

According to residual analysis from Minitab in figure 5.20, the normal probability plots are formed resemble a straight line. The pattern of residuals versus the fitted values plot is non-structure that means the errors have a constant variance. The residuals versus the order of the data plot do not show obvious pattern, therefore the error are statistically independent.

In conclusion, this ANOVA has satisfied all the assumptions that mean this tested is adequate to determine the result.

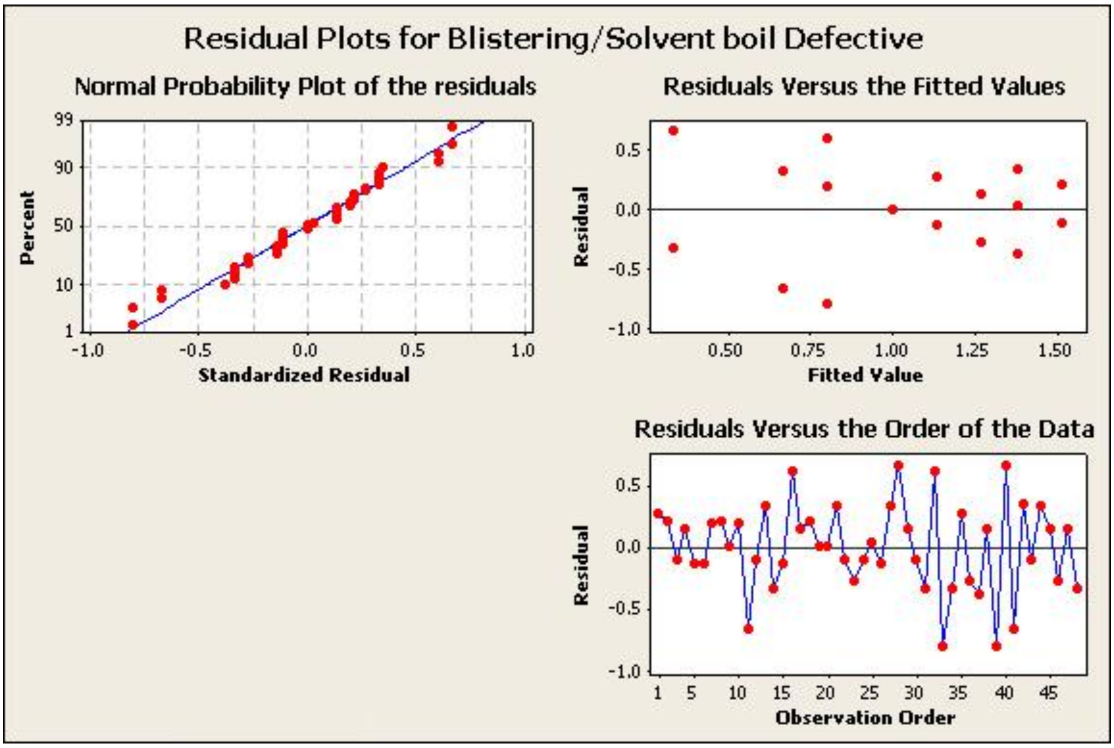


Figure 5.20 Residual plots for blistering/solvent boil defective

5.5 The Experiment Analysis

Factorial Fit: Y versus A, B, C, D

Estimated Effects and Coefficients for Y (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		1.0394	0.06147	16.91	0.000
A	0.3737	0.1869	0.06147	3.04	0.005
B	0.1346	0.0673	0.06147	1.09	0.282
C	-0.3129	-0.1565	0.06147	-2.55	0.016
D	-0.4304	-0.2152	0.06147	-3.50	0.001
A*B	-0.0321	-0.0160	0.06147	-0.26	0.796
A*C	-0.0096	-0.0048	0.06147	-0.08	0.938
A*D	0.0396	0.0198	0.06147	0.32	0.750
B*C	-0.1954	-0.0977	0.06147	-1.59	0.122
B*D	0.2788	0.1394	0.06147	2.27	0.030
C*D	-0.0321	-0.0160	0.06147	-0.26	0.796
A*B*C	0.0396	0.0198	0.06147	0.32	0.750
A*B*D	-0.1229	-0.0615	0.06147	-1.00	0.325
A*C*D	-0.1004	-0.0502	0.06147	-0.82	0.420
B*C*D	-0.0512	-0.0256	0.06147	-0.42	0.680
A*B*C*D	-0.0513	-0.0256	0.06147	-0.42	0.680

S = 0.425872   PRESS = 13.0584
R-Sq = 55.06%   R-Sq(pred) = 0.00%   R-Sq(adj) = 34.00%

Figure 5.21 Blistering/Solvent Boil ANOVA

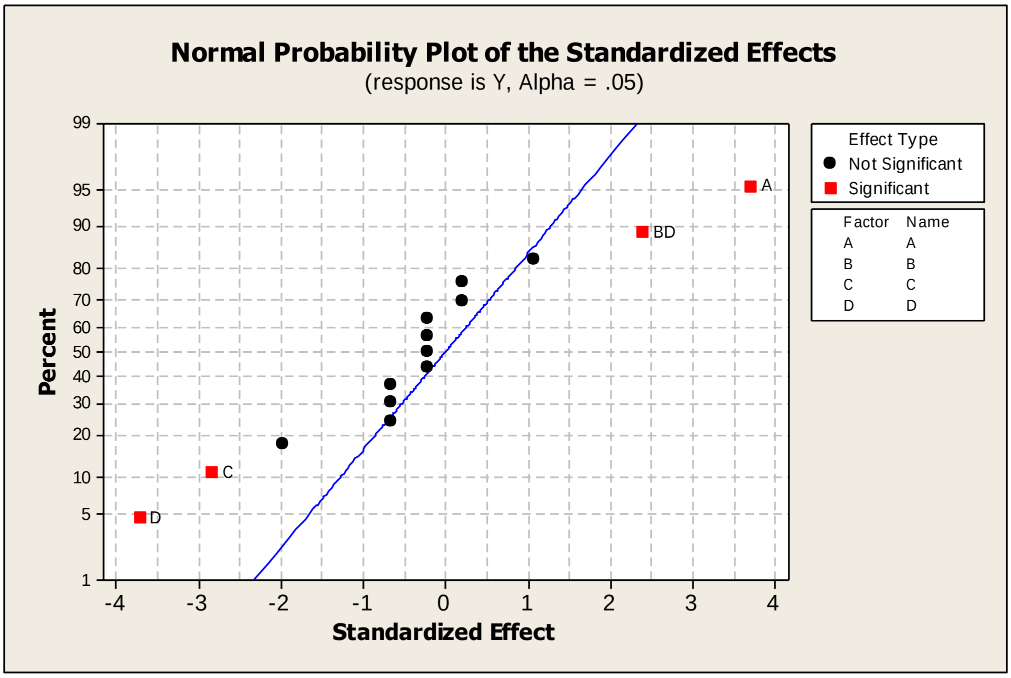


Figure 5.22 Normal Probability Plot of the Standardized Effect

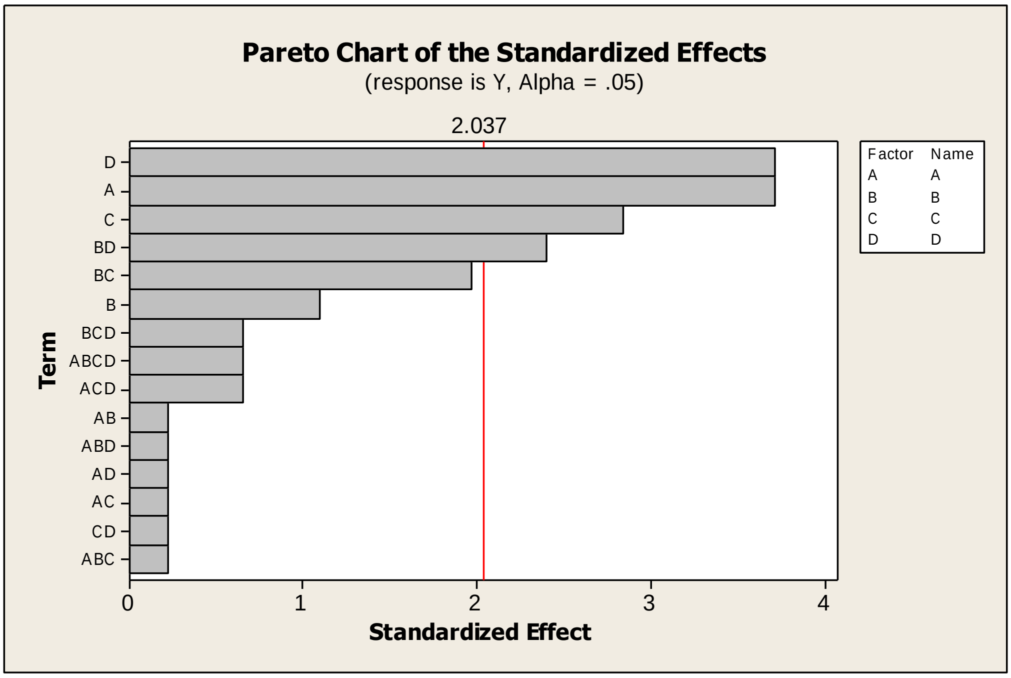


Figure 5.23 Pereto Chart of the Standardized Effects

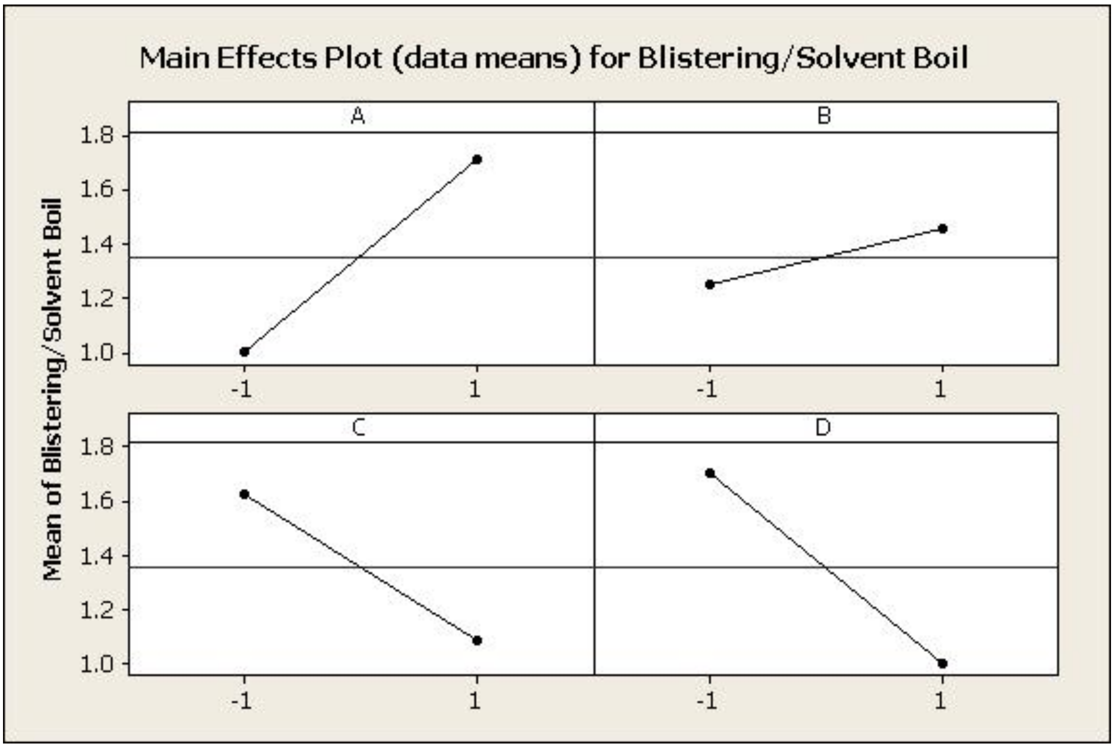


Figure 5.24 Main Effects Plot for Blistering/Solvent Boil

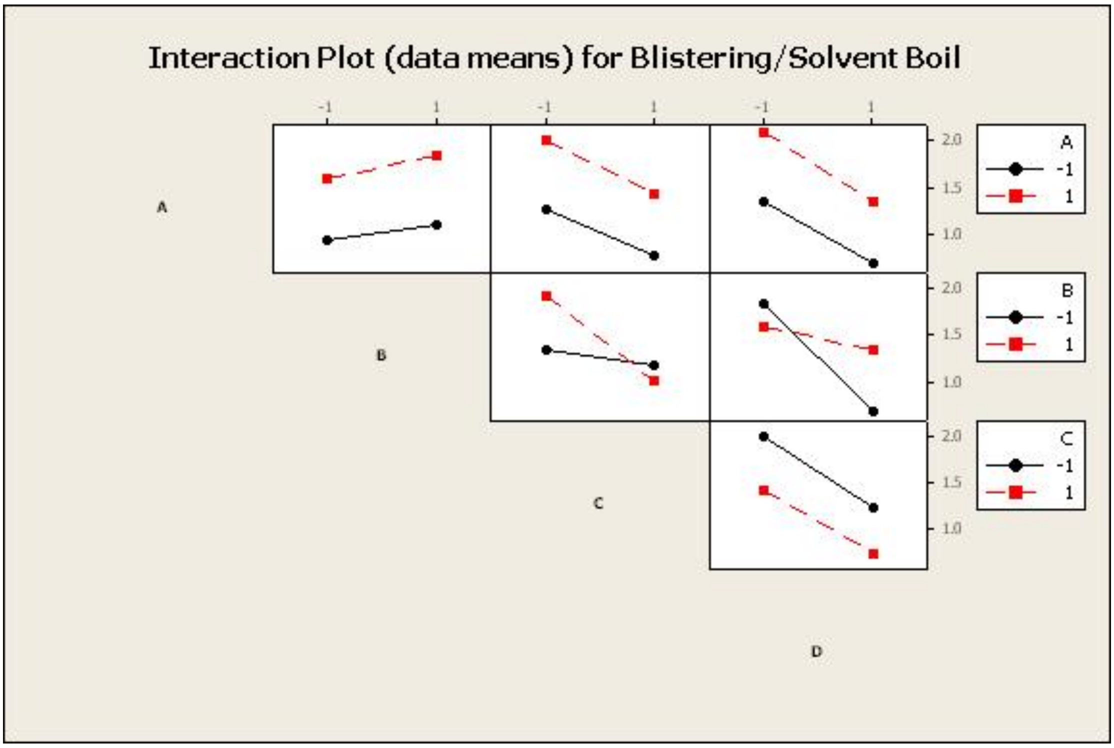


Figure 5.25 Interaction Plot for Blistering/Solvent Boil

According to the data analysed by Minitab, There are three main effects that significantly affect to the defect as shown in figure 5.21, figure 5.22, figure 5.23, figure 5.24, and figure 5.25. The P-value for factor B (Thickness of paint film) is greater than a significance level of 0.05. However, factor B is significantly affect to the defect when factor B combine with factor D (type of reducer) that is describe in next paragraph.

There is one interaction effect for response blistering/solvent boil defect that significantly affect to the defect as shown in figure 5.21, figure 5.22 and figure 5.25, which are interaction between B (Thickness of paint film) and D (type of reducer).

In conclusion, in order to reduce blistering/solvent boil defect in painting process, the recommendations are listed below.

- Compressed air should be filtered by filter/air dryer system.
- Top coat should be painted 2 layers
- The mixing should be blended at least 9 minutes.
- Slow reducer should be used in mixing instead of medium reducer

The best factors levels for reduce blistering/solvent boil defect is shown in table 5.3

Factors		
	Level	Definition
A= Effectiveness of Oil and Vapour Filter	-1	Pass Filter and Air Dryer
B= Thickness of the Paint Film	-1	50-70um
C= Mixing Uniform	+1	Blend 9 minute
D= Type of Reducer	+1	Slow (code: 352-216)

Table 5.3 Best factors levels

5.6 Confirmation Test

The experiment in this section is the experiment to confirm that the significant factors that adjusted to the best factors' level to validate that the blistering/solvent boil and dust contamination defect rates are reduced to the team target.

5.6.1 Objective of the Experiment

To study blistering/solvent boil and dust contamination defect after adjust the painting process with the best factors' level of 8 significant factors that are efficiency of oil and vapour filtration, paint film thickness, mixing blend time, type of reducer, cleanness of paint suit, cleanness of paint booth, type of masking paper and body cleaning.

5.6.2 Preparing of the Experiment

The methods to prepare the experiment are described as following.

1. Prepare 20 of 20*20cm with accuracy +/- 1 mm prepared for topcoat metal sheets and check that it is suitable to be tested that come from the same preparation of previous tests. Since, cost and time consuming, team design to test on only 20 sheets. Each sheet is divided in to 4 pieces of test unit that size 10cm*10cm with accuracy +/- 1mm.

2. Prepare equipment and material of the experiment

3. Run the painting process as working on the new adjustment process.

5.6.3 Results of the Experiment

From the experiment result, defective rate from blistering/solvent boil is 6.25%, comparing with 33.8% before the improvement and defective rate from dust contamination is 28.75%, comparing with 70.16% before the improvement that the defective rate is reduce 81.5% and 59.02% , respectively.

	Defective rate before the improvement (%)	Defective rate after the improvement (%)	Improvement rate (%)
Blistering/Solvent Boil	33.8	6.25	81.5
Dust Contamination	70.16	28.75	59.02

Table 5.4 Before and After Defective Rate

5.6.4 Conclusion

After improving the painting process, by adding air-dryer to the compressed air system, reduce the painting layer from 3 layers to 2 layers that affect to the reduction of film thickness from 80-110µm to 50-70µm, increase mixing blend time from 3 minutes to 9 minutes, replace reducer in mixing formula from 352-91 to 352-216, replace new cleaned paint suit every day, clean painting booth once a week, change masking paper from recycle paper to professional masking paper and painter has to clean himself before entering the paint booth. The result from the improvement is that the blistering/solvent boil defect rate is reduced 81.5% and dust contamination defect rate is reduced 59.02%

CHAPTER VI

Control of Processes

After defect reduction solution was determine, the next step is control the processes and factors that affect to the painting result that the control factors are compressed air filteration, thickness of painting, mixing blending time, type of reducer, Cleaness of painting equipment and operation procedure.

6.1 Compressed Air Filteration

The compressed air that carry color pigment through a spray gun to painting surface is very important to the paint quality. Then the air-dryer system is set up in compressed air system. The value shown in figure 6.1 is measured as the control quality of compressed air system that may be used as a reference value to control the efficiency.

	After Pass Air-Dryer System
Oil in compressed air	1 mg/m^3
Water Vapour in compressed air	N/A
Compressed air Temp	30
Dew Point	- 40
Pressure (bar/g)	6.1

Table 6.1 Standard Quality of Compressed Air System

These values are measured by outside air-dryer service team that will measure every 6 month to keep quality to standard. The last checked date will be marked on the air-dryer that painter is responsible to report to supervisor that the air-dryer system have to be rechecked. However, compressed air temp and pressure is recorded every day. Dew point is recorded every Monday by painter, and then they are filled in the compressed air quality control plan and schedule form as shown in appendix.

6.2 Thickness of Paint film

Too many of thickness of paint film affect to the quality of the painting result. Then, the layers of topcoat are reduced from three layers to two layers with the thickness between 50 and 70 µm. Painter will be trained for new adjustment that painting procedure is the same as previously. Thickness of paint film is randomly checked by supervisor.

6.3 Mixing Blending

Previously, painting estimate blending time by checking viscosity of colour by eyes. In this control plan, timer is used to guide painter the blending time. Timer is set at 9 minutes. Painter has to keep blending until hearing the alarm.

Figure 6.1 Timer

6.4 Type of Reducer

The reducer is changed from medium reducer (Glasurit 352-91) to slow reducer (Glasurit 352-216). Medium reducer is clear off working site and inventory to avoid confuse and workers will be trained to use new reducer that mixing ratio and procedure of slow reducer is the same as medium reducer.

6.5 Cleanness of painting suit

Cleanness of painting is one of the factors that have to be controlled. The new painting suits are stocked enough for painter that they can wear the new cleaned suit every day. The suit cleaning is scheduled once a week by specified worker that is on the same day of worker cloth cleaning is on Saturday as in cleaning plan in table 6.2 and then the cleaning schedule and checklist for equipments and painting booth form shown in appendix has to be checked.

6.6 Masking Paper

The recycled paper is replaced by professional masking paper to use in painting masking process. Recycle paper is clear off working site and inventory to avoid confuse and workers will be trained to use new masking paper that the masking procedure is the same as previously.

6.7 Painting Booth Cleaning

Previously, the painting booth is cleaned approximately once a month. For the control plan, the cleaning schedule is set on Saturday and painter and painter assistant is assigned to this job as in cleaning plan in table 6.2 and then they have to check on the cleaning schedule and checklist for equipments and painting booth form shown in appendix

6.8 Body Cleaning

For the control plan, workers have to be checked that they perform self-cleaning. Workers who enter the painting booth when the booth has been operated have to wear painting suit, cleaning themselves and sign on the self-cleaning form as shown in appendix.

In conclusion, above plan controls painting operation by establish the control plan and checklist and operation form that workers have to follow. Supervisor of restoration-painting department will be assigned to validate workers and lead operation to the plan. In addition, the training is set up to guide workers to the new equipment and new working procedure.

Cleaning Plan for Equipment and Painting Booth					
No.	Equipment	Cleaning Schedule	Check tool	Person in charge	Record Form
1	Spray Gun	Every Day	visual check by eyes	Painter	Cleaning checklist form
2	Painting Equipment (such as,container, Material filter)	Every Day	visual check by eyes	Painter	Cleaning checklist form
3	Painting Suit	Every Satuaday	visual check by eyes	Worker who responsible in Worker Cloth Cleaning	Cleaning checklist form
4	Painting Booth	Every Satuaday	visual check by eyes	Painter and Painter assistant	Cleaning checklist form

Table 6.2 Cleaning Plan for Equipment and Painting Booth (Modified from Thai Version)

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

This research applies several techniques to reduce blistering/solvent boil and dust contamination defect in top coat painting process of vintage car which have 5 steps. The 5 steps are defining the problem, measurement to determine the problem cause, analysis of the problem cause, improvement and correction, and controlling the process. The blistering/solvent boil and dust contamination defect result in surplus cost of wage and raw material for production and rework.

The team operation can improve the rate of blistering/solvent boil and dust contamination defect to only 6.25% and 28.75%, respectively. The details of each step in the research summary are as follows.

7.1 Defining problem summary

From analysis of the current problem situation of painting department, we have found that the rate of defect in spray painting is very high. The average rate of blistering/solvent boil defect in top coat painting process is 33.8% while the dust contamination defect is 70.16%. These defect causes more cost from reworking cost in terms of both time and expense including re-inspection cost. Also, the company has the policy to reduce waste and reduce the time spent in reworking. Thus, improvement of the painting process from blistering/solvent boil and dust contamination defect is the first start.

7.2 Measurement to determine the problem cause summary

In this process, the team member will measure for study the cause of problem. The statistic tools are applied for support the study started by analysing gage R&R used in workings verification to assure the correctness of the data measured. The result of evaluation found that the inspectors have % repeatability, % reproducibility, effectiveness of repeatability and % effectiveness of reproducibility at 100. Thus, the results from the measurement are trustworthy and can be apply for measuring the result from the coming steps.

From the analysis of cause and effect from the Cause and Effect diagram, we have 15 possible input causes for blistering/solvent boil defect and 23 possible input causes for dust contamination defect. We seek for the major factors that bring about the defect by scoring the problems in C&E Matrix. This can filter only factors according to the response that related to defect. After that, prioritize the factorฑ by sorting the total scoring in descending order by Pareto chart. There are 9 major factors for blistering/solvent boil defects and 11 major factors for dust contamination defect which they are 79.64% out of total scoring of both defects.

From using the major factors of both defects in analysis of failure characteristic and effect by using FMEA to study the characteristics of the problems and effects from these factors. Then, sort the RPN score by using Pareto chart for determine the priority of each factor that causes blistering/solvent boil and dust contamination defect. We have found that there are 4 major factors for blistering/solvent boil defect and 5 major factors for dust contamination defect. These factors will be analysed for significance in the next step.

7.3 Analysis of the problem cause Summary

In analyse of problem cause, 9 factors is statistically tested in hypothesis test by Two Proportion at 95% of confidence level to be the information that those factor is the real cause of the problem, or not. Significant test of defect cause conclusion is that factors that significant causes of blistering/solvent boil are efficacy of oil and vapour filtration, mixing blend time, type of reducer. Thickness of painting film is not significantly affected to cause of the blistering/solvent boil defect. However, this factor can't be cut off, since it has to be tested in inter-action between factors in the next step.

The significant causes of dust contamination is cleanness of paint suit, type of masking paper, cleanness of paint booth and neglect of self-cleaning before entering paint booth.

7.4 Improvement and Correctness summary

From the brain-storming and previous statistic data, we conclude that the factors that cause the blistering/solvent boil defect are necessary to do the design of experiment (DOE) to find the correct improvement value and verify the interaction between the factors.

Team have chosen the full factorial design for this DOE which is the most effective experiment with 4 input factors and 2 levels for each factor by repeat the experiment in each treatment combination for 3 times. From the experiment result, we conclude that 3 major factors of blistering/solvent boil defect are much influential in the rate of the defect including efficacy of oil and vapour filter system, blending time in colour mixing, and reducer type since the P-Value is less than 0.05. One pair of input factor has significant interaction effect between colour film thickness and reducer type. The appropriate level of each factor is using air-dryer to increase efficacy of filtering, reducing the layers in spray painting from 3 layers to 2 layers with 50-70 μm thickness, blend the mixed colour at least 9 minutes and selection of the slow type reducer (code 352-216)

The factor that cause dust contamination defect can be improved immediately. The major cause is related to cleanness of tools used in paint booth, appropriate tools selection and cleaning method. Thus, the team is brainstorming to improve the standard in cleaning, tools selection, and appropriate workers procedures.

From the test to confirm the result of improvement of each factor by improving from the result obtained from the analysis, it appeared that the value of blistering/solvent boil defect reduces by 81.5% and the value of dust contamination defect reduce by 59.02%.

7.5 Production controlling summary

In this step, we will record the working standard from the value obtained from the experiment and follow up the workers to follow each standard by organizing the new standard training and establish the form and assign person clearly for each duty. This quality improvement will make the workings has good quality, reduce the cost, and meet the timeline and requirements. The customers will receive the high quality products in the end.

7.6 Limitation of Research

Since the response of this research is the defect number in top coat painting process which is the attribute data type that has not much statistical methods that can be applied in analysis and the limitation of working system, we cannot do the experiment with the real workings. We need to test in the mock up model which has limitation in timing and costing that we cannot do the experiment in large scale.

7.7 Recommendations

For the further improvement, outer sources and factors can be used as improving topics such as other material system selection apart from Glasurit system, Dupont, to compare the quality of 2 systems, or changing the solvent base system to water base system. This research focuses only in-source factors.

In the next improvement, the minor defect quality improvement can be selected such as overspray, runs/sags and run test in overall production not limited in top coat painting process. Also, the management/organization system, human resource and facility which have an effect on quality of the result such as rush orders or too many jobs process that establish the pressure and stress on the responsible person can be selected for improvement. The environment and pollution in working place can be selected for improvement as well.

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Appendix

Self - Cleaning Form

Remark : Person who enters the painting booth has to sign on this form

Date	Name	Time

Paint Booth Cleaning Form (Modified from Thai Version)

Compressed Air Quality Control plan and schedule

Compressed Air Control Check list Month__________

No.	Discription	Person in Charge	Frequency	Date 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	Compressed Air Temp Critical Value > 35° C	Painter	Everyday																															
2	Pressure Critical Value < 6 bar/g		Everyday																															
3	Dew Point Critical Value > - 30		Every Monday																															

Date	Problem	Cause

Remark : Note for error or unusual in check list

Compressed Air Quality Control Plan and Schedule (Modified from Thai Version)

Cleaning Schedule and Checklist for Equipments and Painting booth

Cleaning Plan Check list | Month________

No.	Discription	Person in Charge	Frequency	Date 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	Spray Gun Cleaning	Painter	Everyday																															
2	Painting Equipment Cleaning Container,Blending Stick, Filter,...	Painter and Painter Assistant	Everyday																															
3	Painting Suit	Cloth Washing Worker	Every Satuaday																															
3	Painting Booth	Painter and Painter Assistant	Every Satuaday																															

	Date	Problem	Cause
Remark : Note for error or unusual in check list			

Cleaning Schedule and Checklist for Equipment and Paint Booth (Modified from Thai Version)

BIOGRAHPHY

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