Integration of Statistical Quality Control (SQC) and Fault Tree Analysis (FTA) in the quality control of resina colophonium production in Company X

A L Rucitra and A U F Amna
Department of Agroindustrial Technology, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia

Email: andanrucitra@ub.ac.id

Abstract. Resina colophonium is a product that is produced from the processing of pine sap. This product is widely used for adhesives, additives for beauty products and mixtures of paints and varnishes. One of the companies engaged in the production of resina colophonium is Company X. Production process is an important aspect of the company, so any problems must be avoided to eliminate product defects. One way that can be done to avoid problems in the production process is to carry out proper quality control. The purpose of this study was to analyze the quality control of the production process at Company X. The quality control method used is the integration of the Statistical Quality Control (SQC) method to determine the frequency of problems and Fault Tree Analysis (FTA) to complete identification by looking for the causes of these problems so that problem did not repeat. Based on the results of the quality control analysis, it is found that the most serious problem that affects the quality of the production process lies in the labor aspect with a value number is 38.46% and the root of the potential cause is the number of workers who are not following the current work.

1. Introduction
Indonesia has abundant forest products, one of which is pine wood. Pinewood is a natural product originating from Indonesia with quite abundant availability and is a potential material [1]. The Pinus merkusii plant is the only type of native pine plant originating from Indonesia [2]. Pine plants can produce sap which can be processed into useful products. The sap from the pine plant is obtained from the extraction of cells that come out of the tree tissue which is included in the pine plant species [3].

One of the companies that process the potential of pine resin is Company X, which is one of the factories where the production of pine resin becomes resina colophonium. In the production process, many problems arise threatening the quality of the product, resulting in a decrease in market demand, loss of consumer confidence, and poisoning effects due to product contamination. Therefore, it is necessary to prevent problems in the production process, one of which is by controlling the quality of the production process.

Quality control plays an important role in maintaining product quality. There are various quality control methods used by companies in controlling product quality, one of which is Statistical Quality Control (SQC). This method helps problem solving and decision making from problem identification to the analysis of results or decisions [4]. This statistical method also helps in testing product samples and how to evaluate them [5]. In its application, the SQC method can be integrated with other methods to
complete identification by finding the cause of the problem so that it does not recur. It can be done using the Fault Tree Analysis (FTA) method. The purpose of this study was to analyze the quality control of the production process at Company X.

2. Materials and method
The data processing was performed after the required data was collected, and then the data was processed using the Pareto chart, fishbone diagram and FTA method. Pareto chart and fishbone diagram are part of Statistical Quality Control. The Pareto chart was utilized to determine the number of defective products, and the fishbone diagram was used to analyze the causes of product defects. Then, it was continued with the FTA method to find the most critical risk in the production process to obtain the solutions to these problems immediately. The steps are as follows:

1. Conducting surveys and interviews in Company X
   Preliminary surveys and interviews with 2 employees and the production manager aimed to find out the actual condition of the company that can be used in the formulation of problems that exist in the company and can provide exact direction steps taken next by researchers.

2. Developing a P control chart
   Data related to quality control of resina colophonium is taken from several resina colophonium production processes carried out by Company X which are attributes that influence the P control chart for product data that does not meet company standards. The use of control chart P for defective products is as follows:
   a. Specifies the sample size (k)
   b. Calculating the average value of defective products
   
   \[ p = \frac{\text{Number of defective products (not standards)}}{\text{Production quantity}} \]  
   (1)
   c. Standard deviation (SP)
   
   \[ SP = \sqrt{\frac{p (1-p)}{k}} \]  
   (2)
   d. Calculating control limits (CL), Upper Control Limits (UCL), and Lower Control Limits (LCL)
   
   \[ \text{CL} = p^- \]
   \[ \text{UCL} = p^- + 3SP \]  
   (3)
   \[ \text{LCL} = p^- - 3SP \]
   e. Make each control chart by plotting each data and observing the data

3. Developing a Pareto Chart
   Pareto chart is a bar chart that shows the problem based on the order of the number of events that occur the most to the fewest [6]. So that the Pareto diagram is a tool that can represent the sources of defects that are most often encountered, the types of defects that occur most often, or the causes that occur most often. Pareto charts can also be used to find the 20% types of defects that feed 80% of the defects in the entire production process [7]. So this tool can help companies identify the causes of the biggest defects for repairs. The Pareto diagram in this study is used to determine the production data of colophonium resin in Company X, and the defects that often occur in the colophonium resin production process to focus attention on the factors that have the greatest influence on product defects.

4. Developing a Fishbone Diagram
   Fishbone diagram or Fishbone Diagram is one method to improve quality. This method can see the number of defective products and analysing the impacts of these product defects [8]. Often this diagram is also called a cause-and-effect diagram. Fishbone diagrams (fishbone diagrams) have an internal function, to identify possible causes for a specific effect. This method is also used to display
the elements that result in the product not being in accordance with the predetermined quality parameters. The steps to create a cause-and-effect diagram are as follows:

a. Identify the problem that is used as a backbone influence.

b. Identify the categories of potential causes.

c. Adding supporting branches or bones that can indicate a specific cause

5. Developing a Fault Tree Analysis

After obtaining the priority scale for grouping 80-20% in the SQC results, it is necessary to analyze the causes of the non-conformance process using the FTA method. FTA is a very effective risk assessment tool but when it comes to a reasonably complex system, that includes a large number of equipment and process variables, the fault tree becomes enormous and takes quite a time to be completed [9]. The use of the FTA method serves to identify the root cause of the failure of the production process.

3. Result and discussion

3.1. Quality control

Quality control activities at Company X are specifically carried out with a series of quality tests. Quality testing is carried out by the QC (Quality Control) section with established quality standards. However, in practice, quality control at Company X still refers to the quality standards issued by the Indonesian National Standard (SNI). Testing is more emphasized on the technical aspect, namely in the form of samples used only for a certain period. Quality control of raw materials is carried out by testing pine resin before entering the production process. Tests are carried out in two ways, namely visual tests, and laboratory tests.

3.1.1 Visual test

The principle of visual testing is carried out by technical experts who are experienced in seeing the sap with the naked eye. The equipment and materials used for the visual test include test samples/samples and latex samples with quality standards Super Premium (SP), Premium (P), Quality I rubber, Quality II rubber and test sampling equipment made of stainless steel. The procedure for conducting a visual test is as follows.

a. Remove excess water in the drum before the test is carried out so that the test sample taken is not too dilute which will affect the results.

b. Stir the juice in the drum, then put the test sampler into it

c. The liquid sap taken from the tool is then matched with the sap sample that has been provided.

d. Sap that does not match the sap sample provided is considered not to meet the quality requirements so that it is refused to enter the laboratory test.

3.1.2. Laboratory test

Laboratory test aims to confirm further the sap that has met the requirements of the visual test. This test is divided into dirt and water content tests. The dirt content test is based on the ratio of the number of impurities in the sap. At the same time the water content test is based on the ratio between water and sap.

3.2 Quality control of production process with statistical method

In observing quality control in the production process at Company X, questionnaires were distributed to respondents who are experts in their fields, including the Head of Company X, Production Supervisors and Quality Control Supervisors, then the results of the questionnaires were analyzed statistically using Pareto Diagrams to determine which factors are the most important factors affecting can affect the quality of the production process, while Fishbone diagram is used to analyze the factors that affect the quality of the production process.
Efforts to control the quality of the production process are also seen based on the comparison of production plan data and product realization of X and WW quality resina colophonium yields in 2019 which can be the basis for conducting and supervising quality control activities for the next period. To find out whether Company X's resina colophonium production activities achieve the set quality targets, data on the production plan and production realization of X and WW quality resina colophonium yields in 2019 are obtained in Table 1.

| Months | X (%) | WW (%) | Yield (%) |
|--------|-------|--------|-----------|
|        | Planning | Realization | Planning | Realization | Planning | Realization |
| Jan    | 5  | 4.85883 | 95 | 95.1412 | 72.15 | 72.3945 |
| Feb    | 10 | 2.79635 | 90 | 97.2036 | 72.3 | 72.3474 |
| Mar    | 17.001 | 0 | 82.999 | 100 | 72.4 | 72.2824 |
| Apr    | 30 | 19.7973 | 70 | 80.2027 | 72.45 | 72.4015 |
| May    | 30.4 | 12.7081 | 69.6 | 87.2919 | 72.5 | 72.4412 |
| Jun    | 30.45 | 13.8442 | 69.55 | 86.1558 | 72.55 | 72.649 |
| Jul    | 30.55 | 32.0518 | 69.45 | 67.9482 | 72.6 | 72.6765 |
| Aug    | 21.25 | 22.2779 | 68.75 | 77.7221 | 72.6504 | 73.3824 |
| Sep    | 31.75 | 34.7606 | 68.25 | 65.2394 | 72.7046 | 73.4613 |
| Oct    | 31.4 | 30.3943 | 68.6 | 69.6057 | 72.7 | 73.4439 |
| Nov    | 15.6 | 9.19478 | 84.4 | 90.8052 | 72.3 | 73.3001 |
| Dec    | 10.004 | 3.18984 | 89.996 | 96.8102 | 72.15 | 72.7336 |
| Total  | 25 | 17.0001 | 75 | 82.9999 | 72.5 | 72.9 |

Furthermore, the production plan data and the realization of yield results from colophonium X and WW resins in 2019 were analyzed in graphical form using Ms. Excel. The graph contains month data for a year from January to December on the x-axis and percentage yields on the y-axis. The results of the graph analysis can be seen in Figure 1 below.

![Graph of production plan achievement percentage of quality X and WW resina colophonium yield in 2019.](image-url)
Based on the results of graphical analysis, it was found that in the product realization data the yield of resina colophonium quality X and WW exceeded the production plan made wherein the production plan data, the total percentage yield was set at 72.5%. In comparison, the production realization was 72.9%. The data shows that Company X has succeeded in achieving the planned quality targets/targets. However, the monthly production realization data shows a declining graphic pattern at the end of the year, starting from September to December. It is necessary to look for the problem, starting from what problems often arise, what are the causes of the problem of decreasing the quality of resina colophonium production and what solutions are being carried out by Company X to overcome these problems. Product yield is the number of final products in the process or a comparison of the percentage of products with raw materials [10]. A process that involves an esterification reaction cannot reach a maximum yield of up to 100% because the esterification reaction is able to return to its original form and produce water vapor which can reduce the product yield.

3.2.1 Pareto chart
Making Pareto diagrams for analysis of quality control of the production process is done by distributing questionnaires to respondents who are experts in their fields. The questionnaire is made in the form of a statement of problems that occur in terms of aspects of raw materials, labor, machinery, methods, and the environment which are then given an assessment. 1 which means not often, 3 which means often and 5 which means very often. The results of the questionnaire distribution obtained results as shown in Table 2.

| Problems       | Very Often | Often | Not Often | Frequency | Cumulative | %   |
|----------------|------------|-------|-----------|-----------|------------|-----|
| Labor          | 15         | 0     | 0         | 15        | 15         | 38.46 |
| Machine/ Equipment | 5        | 3     | 1         | 9         | 24         | 61.54 |
| Raw Material   | 5          | 1     | 3         | 9         | 33         | 84.62 |
| Environment    | 0          | 1     | 2         | 3         | 36         | 92.31 |
| Methods        | 0          | 0     | 3         | 3         | 39         | 100  |
| Total          | 39         |       |           |           |            |      |

Figure 2. Pareto diagram of frequency questionnaire results level of frequency of problems.
Based on the results of the questionnaire above, the total frequency of occurrences is 39, which means that problems that occur in factories occur at moderate or frequent frequencies. This assessment is carried out by the respondents. The level of problem is in the range of 15-75. A score of 15 means that the problem does not occur often, but if all respondents consider that the incident occurs frequently, a maximum score of 75 will be given. The calculation of the results of the questionnaire can be interpreted using the rules for the largest value (X) and the smallest value (Y) with the formula [11]:

\[
X = \text{the largest value of Likert} \times \text{the number of respondents} \tag{4}
\]

\[
Y = \text{smallest Likert value} \times \text{number of respondents} \tag{5}
\]

The results of the questionnaire are then made in the form of a Pareto diagram shown in Figure 2. The Pareto diagram above contains data on aspects assessed on the x-axis (direction to the right) and data on the frequency scores of each aspect on the y-axis (upward direction) on the aspect of labor. A Pareto diagram is a tool for interpreting data from the results of determining the relative frequency and ranking of problems and their accompanying causes into a simple presentation [12].

3.2.2 Fishbone diagram
Based on the Fishbone diagram below, the analysis process is carried out on all aspects, starting from the labor aspect which is the most important aspect because it is the most serious problem in the results of the Pareto diagram, then continued analysis on other aspects, namely raw materials, machines, methods, and the environment. In the aspect of labor, the problem that occurs is the lack of manpower on the part of machine operators and transporting sap which has an impact on not optimal work results. This is due to the absence of additional employees in the operator’s section who have retired and labor for wholesale transportation of latex so that some machine operators have to work concurrently and this results in not working optimally as well as achieving the planned quality to be unstable. The Availability of factory workers who are less can cause delays in work activities [13]. This is because a job that should be done by several people can only be done by one or two people whose abilities are limited. Lack of manpower is caused by a lack of expertise and wages provided by the company.

![Fishbone Diagram](image-url)

**Figure 3.** Fishbone diagram.

In the aspect of raw materials, the problem is the lack of supply of raw materials to the factory, so that the amount of production carried out is not in accordance with the production capacity. In addition, the quality of the latex obtained is sometimes also not good so that the achievement of X quality is also less than optimal. Good quality raw materials will produce a good output where one of the successes of
the company's production if it can choose raw materials with good quality. The selection of good raw materials will minimize the occurrence of production process errors [14].

In the aspect of machinery and equipment, the problems that occur are because several times there are machines that are damaged, resulting in delays in the production process and increasing machine maintenance costs. Machines and production equipment experiencing problems with damage will result in a decrease in machine performance so that it has an impact on company losses such as delays in the production process, quality targets are not achieved and increased costs [15]. In the method aspect, the problem is that the desired product quality is not achieved because there are stages of the process that are not in accordance with the procedure. Errors in the production process method can be caused by the low awareness of workers in working according to the given standards [16]. Mistakes were made, especially in the application of standard work and the rules set by the company.

On the environmental aspect, the problems occur in the form of accumulation of waste litter and imperfect WWTP facilities, resulting in an unsightly view in the area around the factory. Wastewater management that is less than optimal will lead to various environmental problems. Inadequate sewage treatment facilities at the factory certainly hinder separating water and sediment, causing unpleasant odors [17].

Based on the results of Frequently Occurring Problems Frequency questionnaires which were distributed to three expert respondents, there are 2 employees and 1 production manager who are very familiar and expert with the production process, while statistical analysis used Pareto and Fishbone diagrams above and obtained solutions for each aspect. The solutions provided by the three expert respondents are expected to be realized so that problems related to product quality can be prevented and reduced. Solutions from the aspect of manpower, including suggestions for additional workers, especially direct labor so that work in the process section is not delayed due to a lack of people. The activity of adding employees aims to ease the workload borne by workers, especially if there are employees who have multiple jobs. This step is considered effective in overcoming workload inequality [18].

Solutions from the raw material aspect include efforts to supply routine and scheduled raw materials to factories and increase the number of suppliers so that there is no shortage of raw materials. Suppliers are an important part of the company's production process because they supply raw materials to factories. It is very important to add suppliers to overcome material shortages. Solutions from the machine and equipment aspect include routine maintenance and maintenance activities for machines as well as the addition of automatic machines to make work easier. Machine and equipment maintenance activities are a necessity because machine maintenance activities can maintain machine performance so that it can continue to work optimally [20].

The solution from the method aspect is that all workers must work according to standards to minimize production errors. The importance of Standard Operational Procedure (SOP) in work can be a guideline for doing work correctly, thoroughly and consistently in order to produce products that meet standards [21]. Finally, the solution from the environmental aspect is the construction and improvement of a better WWTP so that the problem of the waste collection can be resolved. Waste treatment facilities that are appropriate and in accordance with waste management will have an impact on the cleanliness and health of the environment [22]. Waste treatment as an axis in processing waste in order to reduce pollution has benefits for both the factory and the surrounding community.

3.3 Analysis of the causes of non-conformance of the process with the FTA method
The development of a strategy for identifying potential failures in this study was carried out using FTA. 4 potential causes will be identified in more depth using the FTA method. Potential causes identified using the FTA method are lack of manpower, lack of supply of raw materials, damaged machines, accumulation of waste. Based on these potential causes, the next step is to create a fault tree (Fault Tree) which explains the causes of defects in the form of a tree diagram using standard logic symbols [23]. To help reduce process failures, it is necessary to conduct a detailed discussion of the factors that cause failure. The main problem that has the potential to cause the failure of the resina colophonium production
process is the lack of manpower on the machine operator and sap transporter which has an impact on the non-optimal production process carried out. Strategy development on the lack of manpower can be seen in Figure 4.

![Fault Tree Analysis](image)

**Figure 4.** Fault Tree Analysis of less manpower.

Based on Figure 4, it can be seen that the main problem in the resina colophonium production process is the lack of manpower, which results in the production process being carried out not optimally and also the quality of the resulting product is unstable. The rubber that should be done by several workers is only carried out by two workers with limited abilities, this is because there is no substitute for employees who have retired and operators work concurrently with other jobs. From the proposed steps to improve the potential cause using the FTA method, then control is carried out on the biggest problems based on the results of the questionnaire [24]. Control on the value of the biggest problem is intended to focus improvements on the main causes in the resina colophonium production process, namely the lack of manpower with the root of this potential cause being the absence of substitutes for retired employees and operators who work concurrently with other jobs. Companies need to adjust the number of employees in each section, because each employee must do work that should not exceed his workload [25]

4. Conclusions

Based on the results of statistical analysis of quality control using Pareto and Fishbone diagrams and problem analysis using Fault Tree Analysis, it was found that quality control carried out by company X was good and according to standards, but in practice, some deviations occurred during its implementation. The highest problem that affects the quality of the production process lies in the aspect of labor. This is due to the absence of additional employees who on several machine operators must work simultaneously so that some work is constrained and not optimal.

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