Design for improvement of sugar factory performance based on statistical thinking

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Abstract. The amount of sugar production is determined, among others, by the quality of sugar cane and the performance of sugar factory equipment. The quality of sugar cane as an agricultural product is influenced by the quality of sugar cane seeds, soil conditions and climate. The differences in the factors affect the quality of sugarcane production. Sugarcane milling is not based on the quality of sugarcane but on the arrival time to the factory. Under this condition, different sugarcane qualities will be milled together. As a consequence, it may not yield the optimal sugar production. In the sugar production process, equipment performance must always be monitored. Equipment failure will reduce the amount of sugar produced. Therefore, efforts to increase sugar production must consider both factors, namely the variation of input quality and monitoring of equipment performance. One approach in solving this problem is statistical thinking approach. The purpose of the paper is to design the performance improvement of sugar factory based on statistical thinking. The improving activity based on statistical thinking will concentrate on manufacturing process enhancement and problem breaking that rely on realizing and degrading variation. The study shows that the statistical thinking approach potentially able to increase sugar production using process enhancement framework and overcome factory equipment failure using problem breaking framework.

keywords: sugar cane, statistical thinking, improvement, system

1 Introduction

The amount of sugar production is determined, among others, by the quality of sugarcane and the performance of sugar factory equipment. The quality of sugarcane as an agricultural product is influenced by the quality of sugarcane seeds [1], soil fertility, fertilizer management, sugarcane variety, harvesting process, time lag between harvest and milling [2] and climate [3]. The quality of sugarcane seeds is determined, among others, by the age of sugarcane seeds. The age of sugarcane seeds affects the production of sugarcane and the yield produced [1]. Soil conditions and fertilization management can have a direct effect on the quality of sugarcane syrup which can have an impact on the acquisition of sugar in the process of sugarcane processing into sugar [2]. Weather parameters such as rainfall, temperature, sunlight, humidity and so on affect the growth of sugarcane, the sugar produced and the quality of sugarcane syrup [3].

Sugar production process consists of these processes, namely: milling to extract juice from sugarcane, juice clarification, clear juice evaporation, crystallization, centrifugation, drying and packaging. The process of sugarcane milling is not based on the quality of sugarcane but according to the time of arrival of sugarcane to the factory. In this condition, the quality of different sugarcane will
be milled together so as to produce juices with poor quality. As a result, this condition will affect the results of the next processes so that the sugar produced is not optimal.

During the sugar production process, factory equipment performance must always be monitored. The equipment performance monitoring will ensure that the equipment is always in good performance and prevent equipment failure. Equipment failure will reduce the amount of sugar produced [4].

Therefore, efforts to increase sugar production must consider both factors, namely variations in input quality and equipment performance monitoring. One approach to solving this problem is the statistical thinking approach [5]. Statistical thinking views all works as a system built by processes and realizing and degrading variation inside the processes are essentials for success. [5].

In this context, this paper first studied the sugar manufacturing process as a system of interconnected processes, followed by the variation sources that exist in the system, and then the frameworks for understanding and reducing the variation, and finally the conclusion.

2 Material and method
The research method is based on statistical thinking [5] and literature study. The steps in implementing statistical thinking are shown in figure 1 [5].

![Figure 1. Stages in employing statistical thinking [5].](image)

3 Results and Discussion
3.1 The first idea of statistical thinking is that all work happens inside a system built of processes that connected each other
The manufacturing process of raw sugar is a system that consist of the following processes: sugar cane milling, juice clarification, clear juice evaporation, crystallization, sentrifugation, and sugar packaging [6, 7]. In the milling process, the cane will be shredded and crushed to extract juice from the fibrous material. The juice clarification produce clear juice with the lowest concentration of insoluble and soluble impurities. Water is evaporated out of the clear juice by steam to form syrup in the evaporation stage. During the crystallisation stage, the syrup is further concentrated by boiling and seeded with fine sugar crystals. The raw sugar crystals are separated from the mother liquor and then conditioned using air in a rotating drum to yield the raw sugar in sentrifugation stage. The by-product generate from sugar manufacturing process are bagasse (from the milling stage), filter muds (from the clarification stage) and molasse (from the sentrifugation stage). The manufacturing process of raw sugar is shown in figure 2. The inputs, outputs and by-products of the sugar manufacturing process are shown in table 1.
Figure 2. Manufacturing process of raw sugar ([6], [7]).

Table 1. The inputs, outputs and by-products of sugar manufacturing process ([6],[7]).

| Stage          | Input          | Output         | By-product        |
|----------------|----------------|----------------|-------------------|
| Milling        | Sugarcane      | raw juice      | Bagasse           |
| Clarification  | raw juice      | Clear juice    | Filter mud        |
| Evaporation    | Clear juice    | Syrup/liquor   |                   |
| Crystallization| Syrup/liquor   | Raw sugar crystal |                 |
| Centrifugation | Raw sugar crystal | Raw Sugar | Molasses           |

3.2 The second idea of statistical thinking is that there are variation inside all process
From literature study, there are several sources of variation in the sugar manufacturing process. The variation comes from the quality of sugar cane and from the processes during the manufacturing stage.

The quality of sugarcane depends on several factors like seed cane, varieties, age, soil characteristics, and climatic conditions [1,2,3,4, 8]. Sugarcane varieties, weather, harvest handling and post-harvest storage procedures are factors that affect the content of sugarcane impurities such as phenolic acids, pigments and flavonoids. [9].
The quality of cane juice depends on sugarcane quality and the method of extraction [6]. Among the factors that may influence the composition of cane juice are variety, age, climatic condition, cultural practices, soil condition and harvesting time [10]. Harvesting technique have a direct impact on cane juice quality [11]. Further, cane juice quality is affected by soil salinity [12] and sulphur content in the soil [13].

The sugar juice ingredient, the content of inorganic phosphate, the type and state of liming, and the juice components interaction are factors that influence the efficiency of sugar cane purification [14]. These factors are potentially the sources of variation in clarification process.

Variation in evaporation, crystallization and centrifugation stage come from dextran and starch content in cane juice. The existence of dextran inside sugar cane juice will degrade evaporation rate and increase duration of separation in centrifuges [15]. Existence 50-100 ppm of starch in cane juice cause reduction of crystallization and centrifugation rates [15].

3.3 The third idea of statistical thinking is that realizing and degrading variation inside the processes are essentials for success.

The variation that are considered are variation that occur accidentally. Furthermore it is analyzed and utilized to enhance performance. In order to understand the variation and processes that generate it, the variation must be recognized, categorized dan measured. With this knowledge the process will be changed to reduce its variation [5].

Two types of variation that is considered are common cause and special cause variation. Common-cause variation is natural variation that exist inside every process while special-cause variation is beyond natural variation that leads to extreme values. The distinction between these types of variation is shown in table 2. Common-cause approach is used to enhance performance by substantially modifying the process while special-cause approach is used to recovery the unstable process [5].

| Common-cause variation | Special-cause variation |
|------------------------|-------------------------|
| Always exist           | Nonpermanent and unforeseeable |
| Many sources with minor effect | Few sources with major effect |
| Portion of the natural behavior of the process | frequently associated with a certain case |
| Process is stable      | Process is unstable      |

3.4 Statistical engineering

Statistical engineering is a technique to apply ideas, methods, and instruments and integrate them with information technology and other relevant sciences to upgrade outcomes. Statistical engineering is the tactical component that gives integral approaches to break unresolved problems that are appropriate with the ideas of statistical thinking. There are two kinds of statistical engineering frameworks to utilize the strategy of statistical thinking. The framework of process improvement is put forward to solve the common-cause variation in processes that are stable but on unsatisfying states. The framework is shown in figure 3. The problem solving framework is proposed to resolve the special-cause variation. The framework is shown in figure 4 [5].

3.4.1 Design of process improvement framework in sugar manufacturing process. The design of process improvement is based on the framework in figure 3. The stages of improvement are as follows:

3.4.1.1. Understanding the sugar manufacturing process. The process was described in section 3.1 and the flowchart of the process is shown in figure 2. Table 1 describes the inputs, outputs and by-products of the process.
Figure 3. Basic process improvement framework [5].
3.4.1.2. Gather data on input, process, and output of the sugar manufacturing process. Data is recorded from the sugar plant based on table 1. The data is recorded by sugar plant periodically. For example, data collected by sugar plant every day are the quantity of sugarcane, bagasses, filter muds, molasses and raw sugar.
3.4.1.3. **Investigate the stability of the sugar manufacturing process.** Process stability can be assessed using run chart [5]. Run chart for raw sugar production and by-product generation every day will show the stability of the production process. The by-products include bagasses, filter muds and molasses. Stable process means consistent process. Unstable process usually indicates the existence of special causes that their root causes need to be recognized and removed. [5].

3.4.1.4. **Remove special-cause variation.** It will be described in section 3.4.2.

3.4.1.5. **Investigate the capability of the sugar manufacturing process.** The tools for process capability evaluation are histograms and standards [5]. The standards of the sugar manufacturing process can be measured using mass balance model [16].

3.4.1.6. **Study common-cause variation.** Common-cause variation can be analyzed using stratification and statistical inference [5]. The by-product generated in sugar manufacturing process are bagasses, filter muds and molasses (figure 2). The generation of this by-product shows sugar losses in related stages. So, the identification of common-causes variation can be focused on the related stages. For example, if sugar content in bagasses tends to increase then the problem may be in the milling stage.

3.4.1.7. **Analyze cause-and-effect relationships.** The relationships can be studied using experimental design and modeling techniques[5]. The application examples of modeling techniques are artificial neural network model for forecasting sugarcane juice purification by hydrogen peroxide [9] and simulation model for optimization of evaporation process in sugar industry [17]. The variation sources described in section 3.2 can be considered in experimental design and model building.

3.4.1.8. **Plan and apply changes.** After implementation of the improvement framework, data was collected to verify the impact of the framework. It may need to apply the framework several times to reach the desired results.

3.4.2. **Design of problem solving framework in sugar manufacturing process.** The primary issue of the problem solving is on identifying basic causes of unusual behavior, so the focus is on the unusual behavior and not on the entire process. The design of problem solving is based on the framework in figure 4. The stages of problem solving are as follows [5]:

3.4.2.1. **Document the problem.** The run and control chart may assist in detecting timely when the special caused happen. In addition, the charts able to show step by step or abrupt changes. [5]. In sugar manufacturing process, the sudden change in sugar production may be due to the unplanned breakdowns of the crushing mills [4].

3.4.2.2. **Recognize potential root causes.** Cause-and-effect diagram and “5 Whys” can be used to identify the root causes [5]. First, critical failures of the cane milling are separated from trivial failures. Then the root cause analysis is based on these critical failures. The factors that caused these failures were investigated. The important components of these factors are evaluated. The results obtained from the analysis of root causes are validated using the effectiveness of the overall equipment [4].

3.4.2.3. **Select best solutions.** The best solution can be determined by an interrelationship digraph and multivoting [5]Evaluation was carried out to select an effective maintenance strategy by comparing the strengths and weaknesses of the three practical strategies applied to sugarcane milling. The strategy is based on three different aspects, namely condition, total productivity and reliability. The comparison is based on the methods used, objectives and employee support [4].
3.4.2.4. Apply/verify solutions. The chosen strategy in the previous stage will be tested using experimental design. The influence of several factors can be studied using experimental design [5]. If it is not possible to conduct experiments then simulation approach or model building may be applied.

3.4.2.5. Quantify results. After applying the changes, run and control charts are used to show whether the implemented solution is able to resolve the problem. [5].

3.4.2.6. Standardize. To avoid the same problem will occur in the future, the solution must be standardized. Flow charts is used in documenting the standard operating procedures and the employees training is based on this procedure. [5].

4 Conclusion

In this paper a design of performance improvement for sugar factory based on statistical thinking is presented. The study shows that the statistical thinking approach potentially able to increase sugar production using process improvement framework and overcome factory equipment failure using problem solving framework.

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