Increasing Production Efficiency using Karakuri Principle (A Case Study in Small and Medium Enterprise)

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Abstract. The number of Small and Medium Enterprise (SME) in food processing is increasing. It achieves about 70% from the total businesses established in Indonesia. One of the SME produce wingko, a traditional snack from East Java region which made from coconut, glutinous rice flour, and sugar. The process of making wingko consists of mixing, pouring, baking and packaging that mostly done manually by one or two operators. Through an analysis of the existing condition of the production process, it can be concluded that automation could be achieved with the oven machine, supported by conveyor that utilizes the karakuri kaizen method. This study proposes an integration design of material handling and baking machine that appropriate to be implied in the SME. Furthermore, calculation of indicators to measure the successfulness of the automation implementation is also conducted. The new system performs a significant improvement. This machine reduced the cycle time around 39%, especially in mixing and baking process. The manufacturing lead time is decreased about 55 minutes, while the production capacity is increased to 7 units per hour.

1. Introduction

Small and Medium Enterprise (SME) in Indonesia has growing significantly. More than sixty percent of them are doing food processing. It becomes very demanding, as food has been a primary needs of people. In food sector, there are also some unit that focus on producing traditional snacks of Indonesia such as wingko, dodol, pudak and many others. Wingko is made of coconut, glutinous rice flour and sugar. It originally from Lamongan, a small city in East Java Island. However, nowadays some different regions are being the manufacturer of wingko. Thus, it becomes very popular in Indonesia. They also provide various kind of flavour, such as chocolate, durian, and jackfruit wingko.

In this Wingko production, every process is done manually by two operators. For the preparation of the ingredient process, it is mainly done by one operator which is the owner itself. It is because the owner wants to make sure the recipe will be implemented correctly to maintain the quality. The ingredients for making about Wingko are coconut, glutinous rice flour, sugar, egg, spoon of butter, and vanilla extract.

In mixing process, the procedures are done manually. It requires a lot of energy and time of the operator. The baking process is done by utilizing the stove and the pan of cake. Eight wingko can be baked in each pan. However, when there are a lot of order from customer, it will be hard for the operator to finish it quickly as there are only four stoves available and sometimes those four stoves cannot be occupied together. The final process is packaging process which is done by making up the paper box first which already designed and printed, then put the wingko inside the packaging.
This study aims to design an automated baking machine that has larger capacity and feasible to be implemented to a food-processing SME, using karakuri system. Karakuri refers to an automation which rely on natural forces instead of from electrical power supply [1]. [2] stated that karakuri is a sophisticated mechanical contrivances utilising natural energy [8]. Karakuri system will be implemented as the material handling which in form of roller conveyor that can help the operator to move the baking tray to the baking machine immediately. It does not need the baking machine movement. Therefore, the operator can focus to work on the other process, such as mixing and pouring another dough instead of working on the baking process. Once the wingko is baked, it will be transferred again to the operator in mixing department using the roller conveyor. Thus, the operators will not need spend their time to take the tray from the baking machine.

The main objective of this system is to increase the production rate in baking process of wingko. It also reduces the energy expended by the worker as it is using karakuri system. Furthermore, this system helps to eliminate ineffectiveness on motions and worker activities, repetitive actions and non-value added input. This system is expected to increase the overall SME profit in long-term period.

2. Theoretical Framework

2.1. Automation

Automation is defined as the process of following predetermined sequence of operations with little or no human labor, using specialized equipment and devices [3]. Automation consists of three basic components, which are sensors, analyzers, and actuators. A sensor is a device that converts a physical stimulus (e.g. temperature, force, pressure) into a more convenient form for measuring the stimulus. Sensors are used to measure or identify the input of the process as well as to capture the output for feedback control. Based on the variables, sensors can be divided into mechanical (force, torque, velocity, mass), electrical (voltage, charge), thermal, radiation (wavelength, intensity), magnetic, and chemical sensors. The second component, analyzer, is the unit that is in charge of making decisions based on the input and programmed instructions. The third basic component of automation is actuator. An actuator is a hardware device that converts a controller command signal into physical changes. However, in his book called “Automation, Production Systems, and Computer-Integrated Manufacturing”, [4] compared automation and mechanization. It is stated that those two terms are different. Automation refers to a system that can sense input and “think” on its own, therefore reducing the need of human labor. In contrast, mechanization is simply a system involving complex mechanic process to reduce human effort in doing processes. However, the system can’t think and decide on its own [4]. If a karakuri system stands alone, it is more suitable to be called as mechanization as it doesn’t have any analyzer to make decisions. Nevertheless, karakuri still technically “automates” production process especially in material handling and offers many benefits over electronic systems.

2.2. Karakuri

Karakuri is the use of mechanic devices rather than electric, pneumatic, or hydraulic ones. Its name is derived from mechanical dolls in Japan called Karakuri Ningyo that was first mentioned around 17th to 19th century. A famous example of these dolls is the tea-carrying doll. The doll holds a tray and then a tea bowl is put on it. The weight of the tea bowl causes the doll to move its feet using a wound-up spring. After the tea bowl is taken, the weight is gone and the doll moves backward to its first position [5]. Karakuri mechanisms usually use basic mechanisms such as lever, cams, linkages, springs, gears and crank.

The implementation of karakuri falls in the scope of lean manufacturing [7]. Karakuri is also one reinforcement of modular improvement technology in lean production [8][9][10]. Lean
manufacturing is a manufacturing concept that focuses on minimizing waste (muda), which includes transportation, inventory, motion, waiting, overprocessing, overproduction, and defects. In this case, karakuri eliminates waste in the form of worker energy and time for material handling. Although electrical devices and computers have a lot of advantages to offer, karakuri also serves several benefits that may beat them in some cases. First, karakuri is cheaper than a computerized system. However, this depends on the type of materials used for the karakuri design. Second, it is easier to maintain. Electrical gadgetries require specialists such as electrician, programmer, or mechanic in fixing a problem in the system. With karakuri, the problem is easier to fix and may not even require a specialist [6]. However, because of its simplicity, the capability of a karakuri system is limited. Therefore, in production facilities, karakuri is a secondary tool and is often used for material handling.

3. Methods and Material
There are several steps to design the system. Firstly, the list of SME needs and problems were identified. It was supported by the literature review. An improvement idea was defined by then, which considering the karakuri system and higher level of automation.

The proposed karakuri is a complement to an automated baking machine for wingko production. It is a conveyor that utilizes gravitational force to bring the baking tray into the baking machine and also out of it. The components of the karakuri include aluminum, bearings, PVC pipe, acrylic cut, and plain PCB. The karakuri consists of 2 sets of conveyor that are put together using a standing frame. Basically, when a tray is put onto the karakuri board, the board will fall on one side and so will the tray. The tray will go over the top conveyor into the baking machine. Then after the baking has been finished, the tray automatically comes out to the second set of conveyor.

![Figure 1. Overall machine design](image)

The conveyor type of the karakuri is a roller conveyor. In this study, PVC pipes with diameter of 22 mm are used for the rollers. When an item is on a roller, the roller will rotate and cause the item to slide down to the next rollers. After that, each side of the roller is installed to the center of a bearing, which is then set up to the aluminum. The bearing functions to keep the roller still in its position while rotating. So when the roller rotates, it rotates inside the bearing while the bearing stands still inside the frame. The karakuri board that was previously mentioned is made of acrylic cutting. The machine design is drawn in figure 1.

4. Result and Discussion
In this chapter, the suggested production line will be given. It includes several points of suggested line by arranging workstation based on the production process of wingko. However, major change of workstation layout cannot be applied as the workspace is very limited. Other than rearranging the workstation layout, in order to improve the production system of wingko, an automated baking machine can also be applied as it already become a concern of the owner
because of the limitation in equipment. The production line will be integrated with an automated machine called Wingking 2.0. Wingking 2.0 is an integrated wingko baking machine using Karakuri Kaizen, and full automation. The mechanism of the machine is described by figure 2.

![Figure 2. Machine mechanism](image)

Wingking 2.0 will provide a solution for material handling for baking process by using the Karakuri Kaizen method. The components needed to build the karakuri system are a slide conveyor, metal platform, and springs. The technology mainly uses the help of gravity. Since it is designed using the impact of gravity, the karakuri is designed from a high position to a lower position.

![Figure 3. Tray movement in baking machine](image)
The first mechanism of the karakuri is by using a spring and a slanted slide conveyor below it. Above the string, there will be a metal platform which will be the place to put a trace. The metal platform is hold by the spring so it can have a flat surface horizontal with the floor surface. The trace will then be filled with wingko batter and with a certain amount of weight (when the trace is full) the spring will go down so the metal platform will bend and allow the trace to flow and slides using the power of gravity.

The second part for the karakuri has a similar mechanism where there is another flat metal platform hold by a spring in the other side of the baking machine. When the conveyor inside the baking machine passes the tray to the metal platform, the spring will not go down until the tray is fully passed out of the baking machine due to the weight not fulfilled. By then, when the tray already fully goes out, the spring will allow the metal platform to bend slowly and slide the roller conveyor until it comes back to the position of the operator.

The components needed in baking machine, which is fully automated are proximity sensor, limit switch, relay, timer, heater, and conveyor belt. The main baking machine will use proximity sensor to open the door of the heater. The proximity sensor will detect when a tray passes it. The proximity sensor will also give a signal to the whole baking machine where the heating filament will start and also activate a timer. The layer is made with the system of a conveyor so when the baking is done, the tray will be passed through another side of the Wingking 2.0 machine. The timer will give signal to the other side of the wingking 2.0 machine door. The timer will also give a signal to the conveyor to move the tray to the other side of the wingking 2.0 machine. For the baking machine improvement, the activation of the machine is done using the proximity sensor.

From the table 1, it can be seen that after the improvement implied, the cycle time and production time per unit are reduced. The reduced cycle time is occurred in mixing process and the baking process. It is because the automation and karakuri are implemented in the baking process.

The activities that make the difference in the station 2 is in the material handling activity. The time to move the batter container to the baking department is reduced in the improved method. It is because, the operator itself does not need to move from the table (mixing department) to the stove. Here, the baking machine is provided with karakuri for material handling. Therefore, the person just need to place the container on the karakuri beside the mixing department. Then, it will be transferred immediately to the baking machine and the baking process can be started automatically.

| Parameter                                      | Before Improvement | After Improvement | Δ       |
|------------------------------------------------|--------------------|-------------------|---------|
| Cycle time - 1st Station Preparation (seconds) | 702.063            | 702.063           | 0       |
| Cycle time - 2nd Station Mixing Process (seconds) | 1,102.774          | 1,102.217         | 0.557   |
| Cycle time - 3rd Station Baking Process (seconds) | 3,140.626          | 2,257.1           | 883.526 |
| Cycle time - 4th Station Packaging Process (seconds) | 425.115            | 425.115           | 0       |
| Production time (seconds/unit)                  | 671.322            | 545.229           | 126.093 |
| Manufacturing lead time (minutes)               | 626.567            | 572.491           | 54.076  |
| Production capacity (unit)                      | 50                 | 56                | 6       |

In the baking department, there are more activities in the improvement method compared to the initial method. In the initial method, the pouring activity will be done directly on the which placed on
the stove. However, in the improvement method, it needs to be poured to the baking mold first, then the baking mold will be transferred to the baking machine using karakuri.

Similar to the cycle time, the manufacturing lead time is also decreasing. The result shows the reduction is about 55 minutes for the wingko production. As already explained before, the cycle time is reduced greatly in the baking department because of the implementation of baking machine, thus the baking operation is become faster and the material handling procedure become easier. The other factor that also affect the calculation of manufacturing lead time in this case is the set up time.

In the initial condition, based on an interview with the owner, the production capacity is 50 units per day. The production rate per hour in the initial condition is not calculated because the owner is still doing all the processes manually. Meanwhile, for the improved condition, the production rate increases to 7 units per hour. With 1 machine used for 8 hours a day, the SME will have a production capacity of 56 units per day. This indicates an increase of 6 units per day for the improved condition. The increase is initially caused by the decrease of batch processing time. Analysing deeper into the batch processing time, the cycle time of station 3 is greatly reduced from 3,140 to 2,257 seconds, or about 39%. The decrease in the cycle time is, as stated in the previous analysis, caused by the implementation of karakuri for the material handling. In the improved condition, operator does not have to move from the mixing station and the baking station because the material handling is done automatically using the karakuri.

5. Conclusion

The new baking machine has been deployed in this research. It has been also proved an improvement in production performance. The machine reduced the cycle time around 39%, especially in mixing and baking process. The manufacturing lead time is decreased about 55 minutes, while the production capacity is increased to 7 units per hour.

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