Application of Lean Manufacturing Concepts to Reduce Manufacturing Lead Times within the Meatball Production Process

Jiratthavee Wejwitwarakul and Rungchat Chompu-inwai*
Department of Industrial Engineering,
Faculty of Engineering, Chiang Mai University
Chiang Mai, Thailand
jiratthavee.wej@gmail.com, rungchatc@hotmail.com*

Abstract—The case study company, a meatball manufacturer, is having problem meeting customer demand. Therefore, the purpose of this study was to help reduce the case study company’s manufacturing lead times through the application of Lean Manufacturing concepts. Value Stream Mapping was used to identify the key problems to be found across the production process. It was found that the current process used to lower the temperature of the meatballs causes a bottleneck as it takes 16 hours, which represents 92% of the entire production time. To release this bottleneck, a one-half fraction of a 2^4 experimental design was used to determine those parameters that significantly affect the temperature of the meatballs in the meatball cooling processes. As a result, the study established a new process; that before placing the meatballs in the refrigerator, the company should change from cooling them down using blowing air at room temperature, to dropping cold water on them for 10 minutes. Introducing this change reduced the time taken to lower the temperature of the meatballs from 16 hours to 4.5 hours, a reduction of 71%. This new process will allow the company to increase the number of meatballs products manufactured, plus will allow the company to meet customer demands while delivering the same high quality product.

Keywords—Lean Manufacturing; Design of Experiment; Lead Time; Meatball

I. INTRODUCTION

Current lifestyles mean that people rush to work and have limited time available, leading to behavioral changes such as in their eating habits. This has led to a rise in demand for readymade or ready-cooked food. In Thailand, the consumption of readymade food in 2014 increased 5.5 percent over the previous year, representing a total sales value of about 3.4 hundred billion Thai baht [1] (exchange rate: 1 Thai Baht equals to 0.028 US Dollars, as of 28 November 2015). These increases in market demand have affected changes in the food manufacturing sector, which has had to accommodate the needs of customers. According to data for the years 2011 to 2013, industrial production of processed meat products such as pork and chicken meatballs, as well as ham and processed pork products, increased [2], and it can be said that this increase is a measure of the increasing popularity of processed pork products in Thailand. This rise in demand has led to intense competition among enterprises in the processed meat industry, and especially in the production of chilled, frozen and cooked ready-to-eat products.

The case study company is a subsidiary of one of the leading food and agriculture sector companies in Thailand. The company raises livestock and sells related products, both domestically and abroad, and in particular pork meat and pork meatballs, the latter of which are in very highest demand on the market. The company’s management team was interested in improving the pork meatball manufacturing process; since, having observed the current process, could only produce 10 tons of meatballs per month, which was not sufficient to meet customer demand. The case study company’s long manufacturing lead time represents the key factor influencing the company’s ability to respond to customer needs. The longer the duration of the manufacturing lead time, the more production is delayed, reducing the company’s ability to meet customer demands. This leads to waste, both in terms of time and also staffing levels, as well as in other areas.

A literature review found that lean manufacturing techniques are being utilized worldwide to enhance productivity, ostensibly by reducing waste. The definition of lean manufacturing can be found in many works, such as the works of [3] and [4]. Lean manufacturing analyzes processes and activities throughout the production cycle, its aim being to identify and eliminate waste through the use of a pull- rather than push-manufacturing system. Lean manufacturing also focuses on creating the most efficient work flows throughout a production process, aiming for zero waiting times and zero inventories, so as to increase customer satisfaction levels.

A number of organizations in the food industry have applied the lean manufacturing concepts in order to reduce lead times and eliminate waste; and so reduce production costs. This not only enables organizations to reduce the cost of their products by reducing cycle times and eliminating non-value added activities, but also helps organizations gain a competitive advantage. For example, [5] applied lean manufacturing techniques in a case company that manufactures ketchups, sauces and jams, its aim being to eliminate waste from its production and reduce lead times. References [6-8] also focused on reducing lead times

Financial support provided by the Research and Researcher for Industry (RRI) fund 2015, a part of the Thailand Research Fund (TRF).
through the use of lean manufacturing techniques in the food processing industry; helping to, not only analyze the processes and eliminate waste, but also enabling the company to increase its customer base and reduce operating costs. In addition, in the bread manufacturing company, lean tools were used to identify and reduce product defects that occurred in the manufacturing process by up to 20%, and also reduced unnecessary inventory by 18% [9]. It was also able to decrease unnecessary motion by 37% [9]. In another study by [10], lean manufacturing concepts were used to eliminate waste in the biscuit industry; to reduce lead times and inventory levels, as well as improve biscuit quality and meet customer needs in a timely manner. The findings of these studies were consistent with those of [11] and [12], who applied lean manufacturing concepts in the food production processes.

One lean manufacturing tool that allows a researcher to observe process flows and identify waste is Value Stream Mapping, or VSM, which is used to analyze production line processes. Activities are divided into three types: Value Added (VA), Necessary Non-Value Added (NNVA) and Non Value Added (NVA). Many studies have used value stream mapping together with other lean tools in the food industry and found that they were able to reduce manufacturing process lead times as well as respond better to customer demands rapidly [9-12].

Another technique used in the previous studies was the experimental design technique. This technique identifies factors able to improve production processes through the design of experiments. This technique is also well known for making production processes more efficient and effective. The experimental design approach has been used widely in the food production process, such as in a study by [13], in which the experimental design was applied to the production of dried sausages. In this study, the impact of temperature and ingredient levels on product strength was studied using Linear Regression and Analysis of Variance (ANOVA). Another study by [14] used the fractional factorial design to study the effects of process parameters on inulinase production. Likewise, other study by [15] used the fractional factorial design and response surface methodology to determine the impact of various variables on xylitol volumetric productivity. It was found that the design of experiment technique was used extensively to identify the most significant factors. Experimental design was the appropriate technique to use to help develop the processes, methods and conditions needed to improve results.

Therefore, in this study, the aim was to use lean manufacturing concepts and quality improvement tools such as experimental design together, so as to reduce manufacturing lead times and remove bottlenecks in the case study company's production process. The research identified problems and analyzed data based on the use of lean manufacturing techniques, then made recommendations to improve the process, without adversely impacting upon the quality of the meatballs themselves.

II. COMPANY BACKGROUND AND MEATBALL PRODUCTION PROCESS

The case study company produces and distributes pork meat and pork meatball products. The company employs 272 people, of which 250 are factory workers. The factory has a production capacity of 9,312 tons of pork meat and pork meatball products per year. Pork meatballs are the highest selling product, and the company produces 10 tons of these per month. A picture of the pork meatball product is shown in Fig. 1.

![Pork meatballs](image1)

**Fig. 1.** Pork meatballs produced by the case study company

The pork meatball manufacturing process can be divided into six main steps and 20 sub-steps, as shown in Fig. 2:
The details of the pork meatball manufacturing processes are as follows:

1. **Mincing process:** This step starts with the employees preparing the ingredients and equipment ready for mincing the pork. The ingredients include pork, spices, water and ice, and the mixing machine has to be washed and cooled. Once the pork has been minced together with the other ingredients, the resulting mixture is used for the next production step.

2. **Emulsion-Fermentation process:** After the mixture has been obtained, employees place it in the emulsion tank and ferment it for approximately 45 minutes. The tank is kept at a low temperature using ice, as the emulsion has to be kept at a minimum temperature of 13 degrees Celsius. The process is monitored by staff to ensure it meets requirements.

3. **Meatball forming process:** The emulsion meat is placed into a mold and boiled in a forming pot at 60 degrees Celsius for 10 minutes. During the first manufacturing run, employees usually need to adjust the machine and check if the balls meet the target weight, which is 10 grams per ball. This adjustment takes place once only, but a further random weight check takes place to affirm the process can move on to the next production cycle. If there are no errors found, no more settings of the molding machine take place.

4. **Boiling the meatballs:** The meatballs are moved from the molding pot to another pot set at a temperature of 75-77 degrees Celsius. They stay in this pot for 10 minutes, with staff checking the temperature of both pots in order to maintain the appropriate temperatures.

5. **Lowering the temperature of the meatballs:** Two sub-steps are involved in reducing the temperature; which is done by air and in a refrigerator. The details of these sub-steps are as follows:

   **Sub-Step 1** – Reduce the temperature before placing the meatballs in the refrigerator: Under the current process, air at room temperature is used to lower the temperature of the meatballs before placing them in the refrigerator. If the balls are already cooked, staff have to scoop them out of the pot and then place them on to a sieve. Then, air at room temperature is blown across the sieve from bottom, decreasing the temperature of the meatballs from 77 to 35 degrees Celsius on average over a 5 minute period. Due to the physical properties of the product, air cannot be blown for longer than this as it adversely affects the quality of the meatballs; making them dry, rough and dark in color. It also lowers the meatballs’ weight.

   **Sub-Step 2** – Further reduce the temperature by placing the meatballs in the refrigerator: The refrigerator used in this process is set at a temperature of 2 to 7 degrees Celsius. The capacity of each refrigerator is 15 to 20 cycles or 180 to 240 kilograms, and the target is to reduce the temperature of the meatballs to 4 degrees Celsius, prior to them being vacuum packed. According to preliminary data, the temperature of the meatballs when placed in the refrigerator is 35 degrees Celsius.
Celsius on average, and it takes around 16 to 20 hours to reduce this temperature to the target. Throughout this cooling process, staff monitor the temperature to ensure it meets requirements, before the meatballs are packed during the next step.

6. Vacuum packing process: First the meatballs are weighed to make sure they meet the required weight. After that, the meatballs are placed into a vacuum packing machine incorporating a 100% heavy metals monitor, which is used for consumer safety purposes.

Every month, the case study company is able to manufacture and deliver 10 tons of meatball products to its customers, but since 2014 customer demand has increased, reaching 25 tons per month. As a result, the company is now unable to meet customer demand. The company tried to resolve this problem by adding a working shift, increasing from the usual two shifts per day to three shifts per day, in order to increase productivity. This move helped increase output, but some problems arose, such as with broken equipment, labor issues, product quality and a greater variability in the process. The company then found it difficult to predict output levels, because the process was highly variable. This resulted in more waste than before the new work shift was introduced. The company has since cancelled this additional shift and reverted to two shifts per day; focusing instead on improving the current manufacturing process. It wishes to increase production efficiency and reduce production times to meet customer needs. Therefore, the purpose of this study was to help reduce the case study company’s manufacturing lead times through the application of lean manufacturing concepts.

### III. RESEARCH METHODOLOGY AND RESULTS

The research started by studying the current status of the company’s production process and defining the problems to be resolved. A Value Stream Mapping was used to analyze the production process and identify the problems, with guidelines then generated to resolve these problems and control the process. Each study step is described in detail below.

#### A. Studying the Current Conditions at the Case Study Company and Defining the Problems to be Resolved

During this step, the researchers began by ascertaining the needs of the company and collecting the data. The data collected showed that the most important aspect of the process in need of fixing is the meatball production process. The meatball product is the best selling product, taking up 50% of all output out of the three pork products made, these being pork meatballs, fermented pork and ready-cooked pork. After selecting the process to be studied – the meatball production process – the researchers determined the scope of the study with the help of the case study company. The study then researched the end-to-end process, from the mixing of the various ingredients used right up until the product packing stage. The key purpose of the study was to reduce pork meatball manufacturing lead times.

This first step in the research process examined mincing, emulsion-fermentation, meatball forming, boiling and cooling, as well as vacuum packing processes, and it was found that each step in the manufacturing process is performed separately, but with little space in-between the production steps, so as to ensure a steady product quality, and to help easily identify production batch numbers. To account for all aspects of the process, the researchers collected data for 20 batch processes and then averaged the data to find the total average lead time. The total average lead time came to 17.43 hours or 1048.76 minutes. The lead time for each process step was separately identified and considered as value added time, that is, the time spent adding value to the work such as mixing, mincing, molding and boiling. Non-value added time was considered to be time that does not add value to the product, such as transportation, waiting and inspection times (see Table I).

<table>
<thead>
<tr>
<th>Process</th>
<th>VA</th>
<th>NVA</th>
<th>TLT</th>
<th>Percentage of Total Process Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mincing</td>
<td>4.5</td>
<td>1.74</td>
<td>6.24</td>
<td>0.6 %</td>
</tr>
<tr>
<td>Emulsion-Fermentation</td>
<td>45</td>
<td>2.32</td>
<td>47.32</td>
<td>4.6 %</td>
</tr>
<tr>
<td>Meatballs Forming</td>
<td>10</td>
<td>1.2</td>
<td>11.2</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Boiling the Meatballs</td>
<td>10</td>
<td>0.1</td>
<td>10.1</td>
<td>0.9 %</td>
</tr>
<tr>
<td>Cooling the Meatballs</td>
<td>725</td>
<td>242.7</td>
<td>967.7</td>
<td>92.3 %</td>
</tr>
<tr>
<td>Vacuum Packing</td>
<td>2</td>
<td>4.2</td>
<td>6.4</td>
<td>0.6 %</td>
</tr>
<tr>
<td>Total</td>
<td>796.5</td>
<td>252.26</td>
<td>1048.76</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table I. shows a significant issue with the time taken to cool the meatballs, as this constitutes 967.7 minutes or around 16 hours, represents 92.3% of the total process lead time. The total amount of value added time in this step is 725 minutes or 12 hours, and the non-value added time is 242.7 minutes or around 4 hours. Because the meatball cooling process is so inefficient, the entire process faces delays, leading to unnecessary waiting times and waste.

#### B. Creating the Current-State Value Stream Map

After studying the current manufacturing process, a value stream map of the pork meatball production process was developed (see Fig. 3). This map covers the entire meatball production process, from the mincing of the meat right through to the last step; the vacuum packing process. Fig. 3 shows the direction of the materials flows and also gives information on
waste and other problems with the current process, including the bottlenecks found in the meatball cooling process. Fig. 3 also shows the total average lead time of 17.43 hours.

![Current State Value Stream Map](image)

**Fig. 3. Current State Value Stream Map**

**C. Problem Cause Analysis and Creating the Future-State Value Stream Map**

While creating the current state value stream map, a problem was found that needed to be fixed urgently; the bottleneck problem that exists during the meatball cooling process, as this has the potential to adversely affect the product delivery process. Currently, the meatball cooling process takes 16 hours; to reduce the temperature from 77 degrees Celsius to 4 degrees Celsius. This step takes a lot longer than all the other steps put together, representing as it does 92.3% of the entire production time. Therefore, to enhance the company’s ability to deliver goods on time and to the right quality, this bottleneck problem needs to be resolved as soon as possible.

The study’s analysis of the causes of the problems found during the meatball cooling process can be divided into two sub-stages, as follows:

1) First, the researchers examined all those factors that may have an influence on the time taken to lower the temperature of the meatballs, and this was done through the creation and analysis of a cause and effects diagram, as shown in Fig. 4. This diagram was created based on a brainstorming session held among both workers and supervisors involved in the production line process. The analysis was broken down into categories, these being the ‘4Ms’: Man, Machines, Methods and Materials, and ‘1E’, this standing for the process environment.

![Cause and Effects Diagram](image)

**Fig. 4. Cause and effects diagram of the long lead time in the meatball cooling process problem**
Having established the causes of the problems being experienced, as shown by the cause and effects diagram, it was concluded that not every cause could be further analyzed and eliminated. Therefore, a shortlist of causes to be studied was created by ranking their importance and the feasibility of changing them. The researchers and the company management team together defined the criteria to be used for the root cause rating analysis, based on the impact on meatball temperatures, its relevance to product quality and the potential for improvement. The ratings were given three levels, as follows: 1 = Poor, 3 = Moderate and 5 = High. The results of the root cause rating analysis are shown in Table II. The cause chosen for further study in the next step, which was the ineffective pre-refrigeration temperature reduction process, was ranked no.1 through this process. The other causes found may be analyzed in future studies.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Impact of cause on meatball temperatures (A)</th>
<th>Relevance for product quality requirements (B)</th>
<th>Potential for improvement (C)</th>
<th>Total score (=A×B×C)</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inappropriate refrigerator</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Refrigerator air circulation sub-optimal</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Too many meatball batches in the refrigerator</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Lack of knowledge among employees</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Doors of the refrigerator open and closed too often</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Meatball container not appropriate</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Refrigerator broken</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>No standard measurements used</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>75</td>
<td>2</td>
</tr>
<tr>
<td>The environment</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Ineffective pork meatball cooling process; prior to placement in the refrigerator</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>125</td>
<td>1</td>
</tr>
<tr>
<td>Meatballs cool too slowly</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>No method to identify refrigerator performance problems</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>15</td>
<td>4</td>
</tr>
</tbody>
</table>

2) The cause of the meatball cooling process problem was analyzed from the previous steps. To find a solution, during this stage, the researchers began by working closely with the case study company, looking for new ways to lower the temperature of the meatballs before placing them in the refrigerator. The researchers created a future state value stream map (as shown in Fig. 5) which defined the improvement opportunities and the plans to achieve them, as well as included tools to resolve problems. As mentioned earlier, the design of experiment technique was used in the previous studies to identify factors able to improve production processes. Therefore, the future solution incorporates experimental design technique to cool down the meatballs.

![Image](image.png)

Fig. 5. Future State Value Stream Map
D. Improvement

This step was taken to improve the meatball cooling process. The initial temperature of the meatballs before entering the cooling process is 77 degrees Celsius, and the target was for the meatballs to exit the process at a temperature of 4 degrees Celsius. This meatball cooling process step can be divided into two sub-steps, as shown in Fig. 6. Sub-step 1 involves lowering the temperature of the meatballs from their starting point of 77 degrees Celsius to X degrees Celsius before placing the meatballs in the refrigerator. Sub-step 2 involves lowering the temperature of the meatballs further to reach 4 degrees Celsius using a refrigerator. According to Fig. 7, the current process using blowing air at room temperature for 5 minutes could reduce the temperature of the meatballs from 77 to 35 degrees Celsius during sub-step 1, however, it took a long time (around 16 hours) in sub-step 2 to reach 4 degrees Celsius.

Further analysis identified solutions to the problems seen. Improvements aimed at finding new ways to lower the temperature of the meatballs prior to refrigeration were discussed. The researchers then used the experimental design technique to determine those factors affecting the meatball cooling process, and to improve the process, came up with a number of small steps, as follows:

1) Prepare for the experiment: To find new methods to lower the temperature of the meatballs prior to refrigeration, the researchers studied the previous research and found that the other method used to lower the temperature of the meatballs involved soaking them in cool water [16], which was considered consistent with heat transfer principles related to thermal conductivity. High thermal conductivity reflects a greater ability to transfer heat; for example, ice is 2.18 W/m°C, water is 0.58 W/m°C and air is 0.025 W/m°C, which suggests that ice has the highest thermal conductivity level, so can transfer heat the best. However, due to the internal structure of the meatballs, ice could not be used, so the appropriate heat transfer medium to use was water, as it has a higher thermal conductivity level than air, so can take the heat out of the meatballs more rapidly. So, the researchers and the case study company agreed to study the use of water to reduce meatball temperatures before placing them in the refrigerator. This means that the main purpose of this step became to use water to reduce the temperature of the case study company’s meatballs. Afterwards, those factors expected to affect the meatball cooling process using water were analyzed, such as water temperature, water distribution, cooling time and the air flows above the water. Other factors were kept as constant, such as the same set of employees conducting the experiment, and the tools and equipment used. A sample of 1 kilogram in weight meatballs was used in every trial. This experiment was a randomized experiment, meaning the sequence would not affect the results. The equipment used in the experiment had to be able to control these four factors. Therefore, the researchers and the case study company jointly built the experimental equipment (Fig. 8). Tank containing clean water was used, as were, a pipe releasing water drops, a hose to spray the water, a tank containing secondary water, a fan, a high-pressure pump, a tray for holding 1 kg of meatballs and a thermometer.
2) **Conduct the experiment:** A one-half fraction of a $2^4$ design with two replicates was used to determine the factors that significantly impact the temperature of the meatballs in the meatball cooling processes using water. According to the limitations set by the company equipment, the production process, and quality requirements, the factors and factor levels used are shown in Table III. In order to deliver the same high quality product, the meatballs had to pass all the company’s quality check.

**TABLE III.** FACTORS USED DURING THE EXPERIMENT TO REDUCE MEATBALL TEMPERATURES PRIOR TO REFRIGERATION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Factor</th>
<th>Unit</th>
<th>Factor Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Water temperature</td>
<td>Degrees Celsius</td>
<td>Low (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36 (Room temp.)</td>
</tr>
<tr>
<td>B</td>
<td>Water distribution</td>
<td>-</td>
<td>Drops</td>
</tr>
<tr>
<td>C</td>
<td>Time</td>
<td>Minutes</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>Air flow over water</td>
<td>-</td>
<td>No</td>
</tr>
</tbody>
</table>

Concerning the adequacy of the model, residual analysis was carried out and the residual plots are shown in Fig. 9. It was found that points on the Normal Probability Plot for the residuals were grouped in a straight line. The histogram for the residuals was symmetrical around center. Both graphs showed that the residual data was normally distributed. The plots for the residuals versus the fitted values and the plots for the residuals in terms of the observation order do not show any noticeable pattern or tendency. This indicates that the assumptions of independence and a constant variance were satisfied. As a result, it could be concluded that the errors were normally and independently distributed with a mean of zero and a constant but unknown variance, which were in line with the assumptions made as part of the experimental design.

![Residual Plots for Mean Y](image1)

![Half Normal Plot of the Standardized Effects](image2)

As shown in Fig. 10, the analysis during this step showed that all four main factors and some of the interactions between two main factors (AB, AC and AD) significantly affect the meatball’s temperature, to a confidence level of 95%. This was in
line with the analysis of the estimated effects and coefficient of main factors and the interactions between two main factors, and the p-values shown in Table IV. The p-values of the significant terms are lower than 0.05.

<table>
<thead>
<tr>
<th>Term</th>
<th>Effects</th>
<th>Coefficient</th>
<th>p-value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant = 28.192</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Water temperature</td>
<td>-12.705</td>
<td>- 6.352</td>
<td>0.000</td>
<td>significant</td>
</tr>
<tr>
<td>B Water distribution</td>
<td>4.285</td>
<td>+ 2.142</td>
<td>0.000</td>
<td>significant</td>
</tr>
<tr>
<td>C Time</td>
<td>-10.055</td>
<td>- 5.027</td>
<td>0.000</td>
<td>significant</td>
</tr>
<tr>
<td>D Air flow over water</td>
<td>1.375</td>
<td>+ 0.687</td>
<td>0.003</td>
<td>significant</td>
</tr>
<tr>
<td>AB Water temperature * Water Distribution</td>
<td>6.635</td>
<td>+ 3.318</td>
<td>0.000</td>
<td>significant</td>
</tr>
<tr>
<td>AC Water temperature * Time</td>
<td>-2.865</td>
<td>– 1.432</td>
<td>0.000</td>
<td>significant</td>
</tr>
<tr>
<td>AD Water temperature * Air flow over water</td>
<td>1.865</td>
<td>+ 0.932</td>
<td>0.000</td>
<td>significant</td>
</tr>
</tbody>
</table>

In addition, R-Sq – denoting the accuracy of the analysis – was found to be 99.8%. R-Sq(adj) – denoting the accuracy of only those factors affecting the meatball temperature – was 99.62%. The results indicate that the accuracy of the analysis was satisfied. Then, the coefficients shown in Table IV were used to develop equation for predicting the response as shown in (1).

\[
Y = 28.192 - 6.352(A) + 2.142(B) - 5.027(C) + 0.687(D) + 3.318(AB) - 1.432(AC) + 0.932(AD) \quad (1)
\]

3) Determination of Optimum Conditions and Confirmation Test: Each factor’s optimal value was then determined using (1). The factors affecting the meatball temperatures (yielding the lowest meatball temperature) were factors A (Level +1), B (Level -1), C (Level +1) and D (Level -1). This meant dropping water on the meatballs to reduce their temperatures before placing them in the refrigerator at a water temperature of 2 degrees Celsius (cold temperature) was the most effective process, with no air flow over water. The time taken using this new process was 10 minutes. In addition, substituting the optimal value for factors A (Level +1), B (Level -1), C (Level +1) and D (Level -1) in (1), the response Y value was found to be 8.302, meaning that the expected temperature of the meatballs occurring as a result of applying all the factors mentioned above was 8.302 degrees Celsius.

After the factor optimal values had been found, the test to confirm the experimental results was conducted within the actual process, using five samples. For each sample, the temperature data was collected for five different positions on the tray; to find the average temperature of the meatballs. The results showed that the average temperature of the meatballs after the water cooling process was found to be 8.23 degrees Celsius, which was quite close to the expected value produced by (1), as mentioned above (8.302 degrees Celsius).

D. Conclusion and Process Control

It was found that the improvements introduced helped reduce lead times within the meatball manufacturing process by up to 65.8%, from the existing 17.43 hours (1,048.76 minutes) on average, to a new 5.93 hours or 354 minutes. The time taken to cool the meatballs fell from 16 hours to 4.5 hours. Moreover, the time taken on value added activities dropped from 796.5 minutes to 341.5 minutes, and for non-added value activities from 252.3 to 12.3 minutes. During the temperature reduction step, process times dropped from 967.7 minutes to just 272.7 minutes. In addition, the time taken over value added activities decreased from 725 minutes to 270 minutes, and for non-value added activities from 242.7 minutes to just 2.7 minutes, highlighting the relationship that exists between sub-steps in the meatball cooling process, both before and after the improvements had been introduced (Fig. 11).

As shown in Fig. 11, in the existing process, before the meatballs are placed in the refrigerator, air is used to lower the temperature of the meatballs (77 Degree Celsius) for only five minutes. Air cannot be used for longer than this since it will dry-out the product, which is unacceptable in terms of quality standards. Blowing air for 5 minutes is able to lower the temperature of the meatballs to 35 Degrees Celsius, at which point the meatballs are placed in the refrigerator; to further lower...
the temperature until it reaches 4 degrees Celsius. This latter process takes 16 hours. Under the new, improved process –
dropping water on to the meatballs – within 10 minutes the temperature of the meatballs fell from 77 to just 8.3 degrees Celsius.
With the improvements introduced, the meatballs could be placed into the refrigerator at a lower temperature, so the
refrigeration process only took 4 hours and 20 minutes. Fig. 12 shows the meatball production process flow chart after
improvements.

<table>
<thead>
<tr>
<th>No.</th>
<th>Process</th>
<th>Activity Symbol*</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prepare the ingredients</td>
<td>●</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>Mix the ingredients</td>
<td>●</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>Pass to the emulsion stage</td>
<td>●</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>Ferment the emulsion</td>
<td>●</td>
<td>45.0</td>
</tr>
<tr>
<td>5</td>
<td>Temperature inspection</td>
<td>●</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Pass to the forming machine</td>
<td>●</td>
<td>1.3</td>
</tr>
<tr>
<td>7</td>
<td>Form the meatballs</td>
<td>●</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>Pass to the cooker/boiler</td>
<td>●</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>Cook the meatballs</td>
<td>●</td>
<td>10.0</td>
</tr>
<tr>
<td>10</td>
<td>Pass to the blowers</td>
<td>●</td>
<td>0.1</td>
</tr>
<tr>
<td>11</td>
<td>Drop cold water on meatball</td>
<td>●</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>Pass to the refrigerator</td>
<td>●</td>
<td>0.5</td>
</tr>
<tr>
<td>13</td>
<td>Refrigerate: Reduce temp. to 4 degrees Celsius</td>
<td>●</td>
<td>270.0</td>
</tr>
<tr>
<td>14</td>
<td>Temperature inspection</td>
<td>●</td>
<td>1.7</td>
</tr>
<tr>
<td>15</td>
<td>Pass to the packing section</td>
<td>●</td>
<td>1.0</td>
</tr>
<tr>
<td>16</td>
<td>Pack the product</td>
<td>●</td>
<td>2.0</td>
</tr>
<tr>
<td>17</td>
<td>Pass to the metal detector</td>
<td>●</td>
<td>0.5</td>
</tr>
<tr>
<td>18</td>
<td>Inspect the meatball product</td>
<td>●</td>
<td>3.5</td>
</tr>
<tr>
<td>19</td>
<td>Place in the container</td>
<td>●</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* ● = Operation, △ = Transportation, □ = Inspection, □ = Delay, ▽ = Storage

Fig. 12. Meatball production process flow chart (after improvements)

IV. CONCLUSION AND DISCUSSION

In this study, lean manufacturing concepts were applied to reduce pork meatball production lead times at the case study
company, using experimental design technique to make the process more effective and efficient, and in particular helping to
resolve a key bottleneck problem. As a result, this approach was able to help clarify the existing problems and allowed the
researchers to use appropriate tools and methods to resolve them. It also helped clearly identify the changes needed, plus
helped reduce both waste and production lead times.

However, to ensure that the proposed process did not adversely affect product quality, the following tests had to be applied:
1) to test for bacteria, Total Plate Count (TPC) was measured – the required level being less than 1 x 10^5 CFU/ml, and 2) to test
for differences in product quality between the existing and proposed processes, a sensory ‘triangle’ test was carried out. By
applying the TPC test, it was found that the products produced using the new method met the required quality standards, while
using the triangle test to gauge taste and texture differences between the samples, all 50 people found no difference between
the old and new meatball products. The above tests confirmed that no differences in product quality existed between the
existing process and the proposed process. Under the proposed process, product quality passed all the required tests. As a
result, the proposed process change can be introduced to the company’s meatball production process. So, it can be concluded
that the changes in the meatball cooling process recommended will (i) make the process more efficient, and (ii) will not
adversely affect the quality of the product.

As Fig. 13 shows, under the recommended process the lead time is reduced, with in particular the improved pork meatball
cooling process showing significant time and process improvements over the current manufacturing process. Therefore, the
researchers would like to recommend that the case study company lower the temperature of the meatballs prior to entering
refrigeration in accordance with the process recommended here. The improvements suggested to the process by this study –
through which the temperature of the meatballs is reduced using water prior to refrigeration – will help improve the case study
company’s overall performance. In addition, the refrigerator is currently not used appropriately in terms of its basic operating
characteristics, meaning it operates inefficiently and with high levels of variability. This may shorten the lifespan of the refrigerator unit.

![Fig. 13. Lead times for the proposed meatball production process](image)

**ACKNOWLEDGMENT**

The authors would like to acknowledge the cooperation of the case study company and its employees. Moreover, the authors gratefully acknowledge the financial support provided for the research by the Research and Researcher for Industry (RRI) fund 2015, a part of the Thailand Research Fund (TRF).

**REFERENCES**


**BIOGRAPHY**

**Jiratthavee Wejwitwarakul** is a Master's student in the Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand. Her research is focused on lean manufacturing, process and quality improvement, and application of Industrial Engineering (IE) techniques for productivity improvement.

**Rungchat Chompu-inwai** is an Assistant Professor in the Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand. She received her Ph.D. in Industrial Engineering from Oregon State University, USA, in 2006. Her teaching and research interests include lean manufacturing, process and quality improvement, application of Industrial Engineering (IE) techniques for productivity improvement, economic analysis, and development of new innovative and effective pedagogic approaches for Engineering Education.