The improvement of line balancing in the plastic sack production using theory of constraints

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Abstract. This research was conducted in a plastic sack production that is used to package rice or fertilizer. Problems faced by the company are the built-up of work in process and the imbalance of the production line. The research objective is to increase line efficiency of the production process. The stopwatch time study method is used in measuring the time of each element of the task to get the standard working time. Then backward and forward scheduling and line balancing are performed. On the existing line, there are 11 work centres with 11 workers, a smoothing index of 27,813.68 and a line efficiency of 19.42%. The results of balancing the production line using the theory of constraints obtained the best alternative for 11 workers is to form 7 work centres with a smoothing index value of 4,205.41 and a line efficiency of 55.08%. If it is possible to only employ 10 people, the line efficiency can be increased to 64.26% with a smoothness index of 3,142.94.

1. Introduction
Manufacturing companies often deal with differences in capacity between work centres. All work centres must have a balanced capacity wherever possible (there is a good balance of production lines). If a work centre has the smallest capacity than the capacity of another work centre, then the station becomes a bottleneck [1]. The output of the production line is determined by the smallest capacity so that it is a loss for the company if there is an imbalance capacity [2]. Work Measurement could be used to investigate existing problems to increase the productivity [3]. Imbalance of production lines in the food industry can be corrected by applying the Theory of Constraint [4]. Bottlenecks in the textile industry can be overcome and throughput increases with the application of TOC [5, 6]. Improved line balance can also improve the effectiveness of work teams [7].

This research was conducted at a company engaged in the production of plastic sacks that are used to package rice or fertilizer. Production of plastic sacks through 11 processes, namely mixing of raw materials, the printing of plastic sheets, cooling of plastic sheets, cutting of plastic sheets into threads, winding threads, weaving threads into plastic sacks, cutting of plastic sacks rolls, sewing on plastic sacks, printing processes, packing processes and storage process.
The observations show an imbalance in capacity causing an imbalance in the production line and the
difference in the amount of production caused by the bottleneck work centre. There is also stacking in
Work in Process (WIP) on the production floor related to the low capacity of sewing plastic sacks. To
solve this problem, it is necessary to balance the line production of plastic sacks. The improvement
method used is the Theory of Constraints so that the production line becomes more efficient. The
problem of balancing the production line is related to the minimum number of work centres, the
minimum time scale and the maximization of workload balance [8], evaluation and improvement of
production lines to improve work efficiency and correct imbalances in production lines [9,10], and
increase productivity through increased cycle times [3].

2. Method and equipment
This research is categorized as job and activity analysis. Descriptive research in the form of job and
activity analysis is a research that aims to investigate in detail the tasks and work of a person or group
of people to get recommendations for various needs, such as workload balance and efficiency in the use
of time [11]. The object studied is the line production of plastic sacks. The variables used in this study
are [12]:

- Working time is the completion time of one unit or batch of production needed since raw
  materials begin to be processed at the workplace.
- The rating factor shows the performance of workers compared to normal workers.
- Allowance is the time given to the operator due to personal needs, overcome fatigue and other
  obstacles that cannot be avoided.
- Standard time is the time required by a worker who has an average level of ability to complete
  a job in standard working conditions.
- Daily capacity is the number of products that can be completed in one work centre in a day.
- The production target is the number of products that must be completed in one work centre
every day.
- Bottleneck which is a work centre has a smaller capacity than production needs.

The goodness of a work centre can be seen from its Smoothness Index (SI) and Line Efficiency (EL). A
good line balance condition can be seen from the smaller SI and the greater EL. SI and EL can be
calculated using the following formula.

\[
SI = \sqrt{\sum_{i=1}^{k} (C_{t,\text{max}} - C_{t,i})^2}
\]

\[
EL = \frac{\sum_{i=1}^{k} C_{t,i}}{k \times C_{t,\text{max}}} \times 100\%
\]

Where:
SI: Smoothness Index
EL: Line Efficiency
C_{t,i}: Cycle Time for each work centre
C_{t,\text{max}}: Maximum Cycle Time

3. Results and Discussions

3.1. Calculation of Data Uniformity Test and Data Adequacy Test
Data uniformity test needs to be done to find out whether the working time data is within the control
limits (UCL/ Upper Control Limit and LCL/ Lower Control Limit) or out of control. Adequacy test is
performed to find out whether the work time data that has been taken has met the specified accuracy
requirements. In this study, a 95% confidence level was used, and a 5% accuracy level. Data uniformity
test and work time adequacy test shown that the data is uniform and adequate. The uniformity and
adequacy of the transfer time data gave the same result. After the tests, the data can be used in further
calculations. The selected time for the process of producing plastic sacks is shown in Table 1.
## Table 1. Selected Time

| No | Task                          | Operator Time | Machine Time |
|----|-------------------------------|---------------|--------------|
| 1  | Mixing of raw materials      | 60,6          | 646,0        |
| 2  | Plastic sheet printing       | -             | 2.183,3      |
| 3  | Cooling of plastic sheets    | -             | 363,5        |
| 4  | Cutting the plastic sheet into threads | - | 250,6 |
| 5  | Winding threads              | 40,0          | 328,0        |
| 6  | Weaving threads into plastic sacks | 1.083,2 | - |
| 7  | Cutting plastic sack rolls   | -             | 244,6        |
| 8  | Sewing on plastic sacks      | 8.430,0       | -            |
| 9  | Printing process             | 4.188,0       | -            |
| 10 | Packing process              | 624,1         | -            |
| 11 | Storage process              | 235,1         | -            |

### 3.2. Application of Theory of Constraints

#### 3.2.1. Identify the Constraints of a System

At this stage, it is necessary to observe the problem to be solved. This requires a causal trace that is used to identify the underlying causes of the core problem. Based on observations that have been made, the constraints that have been found are arranged in the form of a current reality tree (CRT) diagram to see the causal relationship. From the CRT diagram, it can be seen that the main factors causing the constraints in the production process of plastic sacks during the study were the existence of bottlenecks at the plastic sack sewing station.

#### 3.2.2. The exploitation of Existing Constraints

The second phase aims to build simple solutions and overcome the causes of obstacles that have been found from the CRT diagram. Figure CRD (Conflict Resolution Diagram) can be seen in Figure 1.

### Figure 1. Conflict Resolution Diagram

After the solution is determined to overcome the existing constraints using CRD, the next step is to apply the determined solution. Steps to determine the bottleneck work centre as below:

- Standard Time Calculation:
  
  The recapitulation of standard time calculations for all work centres and the total processing time is shown in Table 2.

#### Table 2. Standard Time and Total Process Time of the Plastic Sack Production Process

| Work Centre (WC) | Allowance (%) | Normal Time (sec) | Standard Time (sec) | Delay Time (sec) | Set-up Time (sec) | Move Time (sec) | Process Time (sec) |
|------------------|---------------|-------------------|--------------------|-----------------|------------------|----------------|--------------------|
| I                | 12            | 60,6              | 646,0              | 0               | 320              | 4              | 1.039              |
| II               |               | 2.183,3           | 2.184              | 0               | 0                | 4              | 2.188              |
Calculation of Time Required: The time needed is obtained from the total processing time multiplied by the production target in one day at each work centre.

Calculation of Available Time: The calculation of available time is obtained from the production capacity multiplied by the total processing time.

Determination of Bottleneck Work Centres: Bottleneck work centres can be seen in Table 3.

Table 3 shows that four work centres are bottlenecks, namely the thread weaving work centre (WC VI), sewing (WC VIII), printing (WC IX) and packing (WC X). From the results of this calculation, it is clear that there are bottleneck constraints and an imbalance in the production time of each station.

3.2.3. Determine Improvements Based on Actual Conditions

a. Scheduling the production process based on the biggest bottleneck work centre
   Scheduling starts from the work centre that has the biggest time difference, which is a plastic sack sewing station. The steps for scheduling production are as follows:
   - Backward scheduling, done at the work centre before the bottlenecks. Schedule arrange backward from cutting plastic sacks to the mixing process of raw materials can be seen in Table 4.

| WC | Task no. | Available Time (sec) | Required Time (sec) | Difference |
|----|----------|----------------------|---------------------|------------|
| I  | 1        | 72,002,700           | 70,652,000          | 1,350,700  |
| II | 2        | 151,628,400          | 148,784,000         | 2,844,400  |
| III| 3        | 25,502,400           | 25,024,000          | 478,400    |
| IV | 4        | 17,671,500           | 17,340,000          | 331,500    |
| V  | 5        | 41,718,600           | 40,936,000          | 782,600    |
| VI | 6        | 119,249,150          | 120,088,000         | -838,850   |
| VII| 7        | 33,402,600           | 32,776,000          | 626,600    |
| VIII| 8      | 615,334,820          | 697,612,000         | 82,277,180 |
| IX | 9        | 335,071,650          | 344,964,000         | -9,892,350 |
| X  | 10       | 58,963,100           | 62,356,000          | -3,392,900 |
| XI | 11       | 18,572,400           | 18,224,000          | 348,400    |

| WC | Total Process Time (sec) | Delay Time (sec) | Set-up Time (sec) | Move Time (sec) | Standard Time (sec) | Start Time (sec) | Finish Time (sec) |
|----|--------------------------|------------------|------------------|----------------|---------------------|-----------------|------------------|
| VII| 482                      | 99               | 105              | 33             | 245                 | 6.218           | 6.463            |
| VI | 1,766                    | 288              | 194              | 66             | 1,218               | 4.452           | 5.670            |
| V  | 602                      | 79               | 107              | 42             | 374                 | 3.850           | 4.224            |
| IV | 255                      | 0                | 0                | 4              | 251                 | 3.595           | 3.846            |
| III| 368                      | 0                | 0                | 4              | 364                 | 3.227           | 3.591            |
• Scheduling at the Bottleneck Work Centre carried out at the work centre sewing process of plastic sacks shown in Table 5.

| WC | Total Process Time (sec) | Delay Time (sec) | Set-up Time (sec) | Move Time (sec) | Standard Time (sec) | Start Time (sec) | Finish Time (sec) |
|----|--------------------------|-----------------|------------------|----------------|---------------------|-----------------|-------------------|
| VIII | 10.259 | 325 | 95 | 36 | 9.803 | 6.919 | 16.722 |

• Forward scheduling performed for work centres after the bottleneck, starting from the printing station to the final process. For scheduling the work centre from the printing process until the storage process can be seen in Table 6.

| WC | Total Process Time (sec) | Delay Time (sec) | Set-up Time (sec) | Move Time (sec) | Standard Time (sec) | Start Time (sec) | Finish Time (sec) |
|----|--------------------------|-----------------|------------------|----------------|---------------------|-----------------|-------------------|
| IX | 5.073 | 93 | 131 | 35 | 4.814 | 16.981 | 21.795 |
| X | 917 | 189 | 0 | 18 | 710 | 22.002 | 22.712 |
| XI | 268 | 0 | 0 | 9 | 259 | 22.721 | 22.980 |

Based on the scheduling results, the total time needed to meet the production target in one day is recalculated and the time available is then compared to see if there are still bottleneck stations. Calculation of the time required based on the production time scheduling results can be seen in Table 7.

| WC | Process Time (sec) | Available Time (sec) | Required Time (sec) | Difference |
|----|-------------------|----------------------|---------------------|------------|
| I | 715 | 49.549.500 | 48.620.000 | 929.500  |
| II | 2.184 | 151.351.200 | 148.512.000 | 2.839.200 |
| III | 364 | 25.225.200 | 24.752.000 | 473.200 |
| IV | 251 | 17.394.300 | 17.068.000 | 326.300 |
| V | 374 | 25.918.200 | 25.432.000 | 486.200 |
| VI | 1.218 | 82.245.450 | 82.824.000 | -578.550 |
| VII | 245 | 16.978.500 | 16.660.000 | 318.500 |
| VIII | 9.803 | 587.983.940 | 666.604.000 | -78.620.060 |
| IX | 4.814 | 317.964.700 | 327.352.000 | -9.387.300 |
| X | 710 | 45.653.000 | 48.280.000 | -2.627.000 |
| XI | 259 | 17.948.700 | 17.612.000 | 336.700 |

Based on the table above, it can be seen that bottlenecks still occur in all four stations, namely the process of weaving thread into plastic sacks, sewing, printing, and packing, but there is a reduction in the difference in bottleneck time at each station. Because bottlenecks still occur then proceed to the next step.

b. Dividing the Work Element Balanced
The first thing to do to divide the work elements so that they are balanced is to look at the actual conditions of the work elements of each work centre. The total time per work centre can be seen in Table 8.

| WC | Task no. | Standard Time (sec) | No. of Worker | Cycle Time (sec) |
|----|----------|----------------------|--------------|-----------------|
| 1  | 1        | 715                  | 1            | 715             |
| 2  | 2        | 2.184                | 1            | 2.184           |
| 3  | 3        | 364                  | 1            | 364             |
| 4  | 4        | 251                  | 1            | 251             |
| 5  | 5        | 374                  | 1            | 374             |
| 6  | 6        | 1.218                | 1            | 1.218           |
| 7  | 7        | 245                  | 1            | 245             |
| 8  | 8        | 9.803                | 1            | 9.803           |
| 9  | 9        | 4.814                | 1            | 4.814           |
| 10 | 10       | 710                  | 1            | 710             |
| 11 | 11       | 259                  | 1            | 259             |
|    | **Total**| **20.937**           | **11**       | **20.937**      |

Smoothness Index 27.813,68
Line Efficiency 19,42%

From the above calculations, it can be seen that the efficiency of line production is still very low, so we look for alternative improvements. Alternative improvements to existing constraints are sought by the line balancing approach. The preparation of the work centre is adjusted to the actual conditions in the field and it is hoped that the smoothing index criteria will be smaller and the value of the line efficiency will increase.

- Alternative 1 and alternative 2

Alternative arrangements of proposal 1 and 2 can be seen in Table 9.

| Task no. | Standard Time (sec) | Alternative 1 | Alternative 2 |
|----------|---------------------|---------------|---------------|
| WC       | No. of Worker       | Cycle Time (sec) | WC | No. of Worker | Cycle Time (sec) |
| 1        | 715                 | 1             | 1             | 3.514         | 1             | 3.514         |
| 2        | 2.184               | 1             | 2             | 374           | 2             | 374           |
| 3        | 364                 | 1             | 3             | 374           | 1             | 374           |
| 4        | 251                 | 1             | 4             | 245           | 1             | 245           |
| 5        | 374                 | 2             | 5             | 9.803         | 5             | 2.451         |
| 6        | 1.218               | 3             | 6             | 4.814         | 6             | 4.814         |
| 7        | 245                 | 4             | 7             | 710           | 7             | 710           |
| 8        | 9.803               | 5             | 8             | 259           | 8             | 259           |
| 9        | 4.814               | 6             | 9             | 9.185,04      | 11            | 13585         |
| 10       | 710                 | 7             | 10            | 9.918,99      |               |               |
| 11       | 259                 | 8             | 11            | 26,70%        | 35,27%        |

The smoothing index value and the efficiency of the line are better than the actual condition for alternative 1 but it is not desirable to reduce the workforce so a second
alternative is needed. The table above shows that in the proposed alternative 2 work centres remain as numbered as in alternative 1, but there is no reduction in the operator from the actual condition because the workforce is allocated to the sewing station so that the number of sewing workers is 4 operators, with consequences, need an additional sewing machine.

- Alternative 3 and alternative 4
  Alternative arrangements of proposal 3 and 4 can be seen in Table 10.

| Task no. | Standard Time (sec) | WC | Alternative 3 | WC | Alternative 4 | Cycle Time (sec) | Cycle Time (sec) |
|----------|---------------------|----|---------------|----|---------------|-----------------|-----------------|
| 1        | 715                 | 1  | 1             | 1  | 2.899         |                 |                 |
| 2        | 2.184               | 1  | 1             | 2  | 1             | 989             |
| 3        | 364                 | 1  | 1             | 3  | 1             | 1.218           |
| 4        | 251                 | 1  | 1             | 4  | 1             | 245             |
| 5        | 374                 | 1  | 1             | 5  | 1             | 2.451           |
| 6        | 1.218               | 1  | 1             | 6  | 1             | 2.407           |
| 7        | 245                 | 1  | 1             | 7  | 1             | 1.463           |
| 8        | 9.803               | 1  | 1             | 8  | 1             | 2.451           |
| 9        | 4.814               | 1  | 1             | 9  | 1             | 2.407           |
| 10       | 710                 | 1  | 1             | 10 | 1             | 1.218           |
| 11       | 259                 | 1  | 1             | 11 | 1             | 2.899           |
| Total    | 20.937              | 11 | 11178         | 11 | 11178         |                 |                 |

In alternative 3, seven work centres were formed with 11 permanent employees. In alternative 4, seven work centres are formed with 11 permanent employees. The line efficiency and smoothness index are better than the previous alternatives.

- Alternative 5
  Alternative arrangements of proposal 5 can be seen in Table 11.

| WC | Task no. | Standard Time (sec) | No. of Worker | Cycle Time (sec) |
|----|----------|---------------------|---------------|-----------------|
| 1  | 1        | 715                 | 1             | 2.899           |
| 2  | 2        | 2.184               | 1             | 989             |
| 3  | 3        | 364                 | 1             |                 |
| 2  | 4        | 251                 | 1             | 1.463           |
| 3  | 6        | 1.218               | 1             | 2.451           |
| 7  | 7        | 245                 | 1             | 2.407           |
| 4  | 8        | 9.803               | 4             |                 |
| 5  | 9        | 4.814               | 2             |                 |
| 10 | 10       | 710                 | 1             |                 |
| 11 | 11       | 259                 | 1             | 969             |
In alternative 5, six work centres are formed with the number of workers being 10 people. The line efficiency and smoothness index are better than the previous alternatives.

3.2.4. Evaluation of System Constraints Changes in line efficiency can be seen from the five alternatives made. Alternatives 1 to 4 show an increase in line efficiency and smoothness index with the number of workers being maintained at 11 people. A better alternative is found when it is possible to reduce the workforce to 10 in alternative 5.

3.2.5. Return to Step Two and Avoid Inertia The theory of constraint steps taken to overcome the constraints of imbalance in the line production path have found alternative improvements through the application of line balancing. There were seven work centres formed and 11 permanent employees with a smoothness index of 4205.41 and line efficiency of 55.08%. If it is possible to only employ 10 people, the line efficiency can be increased to 64.26% with a smoothness index of 3142.94.

4. Conclusions Conclusions can be drawn as follows:

- The existing production line has 11 work centres with a smoothing index value of 27813.68 and a line efficiency of 19.42%, still far from good line criteria, namely a smoothing index that is close to 0 and 100% efficiency.
- The line production improvements resulted in five alternatives, where the best alternatives obtained are seven stations and the number of permanent workers was 11 people with a smoothness index of 4205.41 and a line efficiency of 55.08%. If it is possible to only employ 10 people, the line efficiency can be increased to 64.26% with a smoothness index of 3142.94. It is needed additional machines or tools for work centres where the number of operators is increased.

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