Model for Assembly Line Re-Balancing Considering Additional Capacity and Outsourcing to Face Demand Fluctuations

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Abstract. The most critical stage in a garment industry is sewing process, because generally, it consists of a number of operations and a large number of sewing machines for each operation. Therefore, it requires a balancing method that can assign task to work station with balance workloads. Many studies on assembly line balancing assume a new assembly line, but in reality, due to demand fluctuation and demand increased a re-balancing is needed. To cope with those fluctuating demand changes, additional capacity can be carried out by investing in spare sewing machine and paying for sewing service through outsourcing. This study develops an assembly line balancing (ALB) model on existing line to cope with fluctuating demand change. Capacity redesign is decided if the fluctuation demand exceeds the available capacity through a combination of making investment on new machines and outsourcing while considering for minimizing the cost of idle capacity in the future. The objective of the model is to minimize the total cost of the line assembly that consists of operating costs, machine cost, adding capacity cost, losses cost due to idle capacity and outsourcing costs. The model develop is based on an integer programming model. The model is tested for a set of data of one year demand with the existing number of sewing machines of 41 units. The result shows that additional maximum capacity up to 76 units of machine required when there is an increase of 60% of the average demand, at the equal cost parameters.

1. Introduction
Assembly line is an important part of the overall manufacturing system. In general assembly line design has the objective to put the elements of the assembly operations on the work stations so that the time required for each work station balanced and equal to cycle time. The issue of balancing of the assembly line, according to Baybars [1] can be divided into Simple Assembly Line Balancing Problem (SALB) and General Assembly Line Balancing Problem (GALB). In the first group, the issue of balancing the assembly line is only limited by the cycle time and technology constraints or sequence of the assembly process. On the other hand, in GALB, the balancing issues are to consider practical limitations that exist in the real assembly line as the line shape, constraints on the availability of the space, parallel stations, and so on.

The main purpose of assembly line design in general is improving the efficiency of the track to maximize the ratio between throughput and cost required [2]. In simple terms this is done by balancing the working time at each work station to the overall line cycle time so that the issue of design is often expressed as a balancing assembly line.

Chen et. al [3] conducted a study on balancing the assembly line in the garment industry. The paper considers differences in skill levels of operator in each work station and use a genetic algorithm to solve it. Research on balancing line in the assembly of the garment industry considering fluctuating demand...
has been made by Samadhi and Totong [4]. In that study, a model of assembly line balancing of a single product that takes into account fluctuations in demand is made. Fluctuating demand is addressed by providing a backup facilities in the form of a sewing machine. Thus the models produce optimal number of sewing machines needed to deal with fluctuations in demand and also the allocation of assembly elements into work station so getting a balanced assembly line. In the model, the unmet demand is regarded as a lost sale and sewing machines that have been held but unused at the time of low demand condition be charged a penalty fee of idle machine. The performance measures are minimizing the overall cost models which include the cost of lost orders, the cost of the idle machine, in addition to the operating costs of assembly, machine fixee cost and cost of installation of assembly station.

If there is a large demand changes with the new pattern will not be met by providing a backup resources, the model developed by Samadhi and Totong [4] will have a weakness because there will be more loss of demand that occurs. In addition, significant changes in demand require the company to do the rebalancing taking into account the specific capacity expansion as well as considering the use of outsourcing.

2. Problem definition
Changes in demand, especially increased demand requires additional capacity which means the action is also redesigning the assembly line. In the garment industry, capacity additions in the form of a new sewing machine is still possible along the available space to put the new sewing machines on the assembly floor. Additional capacity can also be done through outsourcing. Thus, the problem in this research is the determination of additional capacity through the addition of the sewing machine and outsourcing so that it can meet demand as much as possible and minimize costs by assembling a balanced line.

As for the limitations and assumptions used in this research problem is:
• assembly systems using progressive bundle system in the form of a straight line;
• each assembly operation is only performed at one work station;
• the order of operations do not violate the precedence constraints;
• capacity is added in the form of sewing machines in the amount which has a maximum limit corresponding to limited space available;
• the outsourcing company has a limit on the number of products that can be produced;
• line is designed for a single product;
• the costs involved are fixed;
• demand fluctuates but is known with certainty.

3. Model Development
Many studies on assembly line balancing which implicitly states that the case involves a balancing of the new assembly line. But in reality this hardly ever happens, most of the real world task involves balancing the existing line and placed in the existing plant. The needs arising from changes in the products, models that are assembled on the same line, assembly technology, available labor, production targets or demand [5]. When companies face a shortage that may be of production capacity, the company can expand its capacity by investing in new machine fixed by adding capacity even though it took a long and high costs [6] as well as pay the costs through outsourcing [7].

Pinto [8] developed a model for balancing the assembly line at an uncertain demand conditions by considering additional facilities and additional manpower. This model aims at minimizing the total cost consists of fixed costs and labor costs, with a cycle time that is given. Malakooti [9] introduced the model to determine the best alternative in designing a work station on the assembly line where the assembly line developed by the buffer with the formulation of a single criterion method of decision
making. Meanwhile Amen [10] produced a model of line balancing assembly for determining the
placement operation at work station, determination of the number of work stations and the number of
machines. Model adds the cost of machinery and transport facilities costs into the calculation of the total
cost and the proposed branch and bound algorithm to solve the problem.

This model was developed for the purpose of deciding to add capacity and the amount of outsourcing
to meet fluctuating demands that come with a changing pattern in the coming period. Changes in the
pattern is of course in the form of an increase in demand which requires redesigning the existing
assembly line. Development of a model made to the basic model is a model that has been developed by
Samadhi and Totong [4] are already considering fluctuations in demand in the design of the assembly
line. On this model, known cycle time that is used to determine the optimal number of work stations by
placing assembly operations to each work station on the assembly line. Model formulate an objective
function to minimize the total cost of the track assembly in order to obtain optimal order quantity as a
trade off between losses due to lost sales at a cost of idle capacity.

The model developed by Samadhi and Totong Samadhi [4] used for the garment industry. Basically
the model can be said to define the assembly line of installed capacity that can meet fluctuating demand
at a minimal cost. Furthermore, with an installed capacity on the model, at a certain time fluctuating
demand patterns that come in the next period will be amended or will even exceed the production
capacity of existing companies. This model has not been able to produce a decision that should be taken
if a change in the pattern of fluctuating demand, necessitating the development of models that can
anticipate all changes in demand patterns that come and can meet all the demand.

The model developed in this research is using the results of the installed capacity in the basic model
[4] as a parameter. With the parameters of the installed capacity, the research model decided the addition
of machine to meet the order quantity. This model produces optimal order quantity as a trade off between
alternative to adding capacity and outsourcing to meet the fluctuating demands of the consumer. The
balance is done by placing the operation to each work station so that the total time of the operation in
each work station does not exceed the specified cycle time.

If the average fluctuating demand which came less than or equal to the period of the previous demand,
then the optimal number of machines used to perform the process is the optimal number of machines
that are already available based on the calculation of the basic model. However, if the available capacity
is not able to fulfill the demand that comes, then the production capacity should be increased based on
fluctuations of the request. When the company face a shortage of production capacity, an expansion
work station with the addition of capacity at existing work stations can be made by adding sewing
machine. There are limitations for additional capacity thus management may consider other alternatives
for the purpose of meeting the demand by outsourcing to other companies.

3.1. Notation
The notation used in the model developed in this research is as follows:

Index
\[ i \quad \text{: index for task or operation, } i = 1, 2, \ldots, I \]
\[ j \quad \text{: index for machine, } j = 1, 2, \ldots, J \]
\[ k \quad \text{: index for work station, } k = 1, 2, \ldots, K \]
\[ t \quad \text{: index for demand period, } t = 1, 2, \ldots, T \]

Parameter
\[ P \quad \text{: production time per day (minutes/day)} \]
\[ a \quad \text{: assembly cost (Rp/minutes)} \]
\( b \) : cost of the machine (Rp)
\( c \) : additional machine cost (Rp/machine)
\( d \) : capacity cost (Rp/machine)
\( e \) : outsourcing cost (Rp/pieces)
\( f \) : transportation cost (Rp/delivery)
\( st_i \) : time needed to produce 1 unit of job in task \( i \), \( i = 1, 2, ..., I \)
\( Cyc \) : cycle time (minutes)
\( D_t \) : demand on period \( t \) (pieces), \( t = 1, 2, ..., T \)
\( m_i \) : number of machine available for completing task \( i \) at previous period (unit), \( i = 1, 2, ..., I \)
\( WS \) : number of work station available at previous planning period
\( Pred \) : set of predecessor tasks and proceeding task.

**Decision Variables**
\( X_{ik} \) : 1 if task or operation \( i \) assigned at station \( k \), 0 if not, \( i = 1, 2, ..., I \) and \( k = 1, 2, ..., K \)
\( Q \) : number of orders
\( O_t \) : number of orders outsourced at period \( t \)
\( JM \) : number of machines
\( MB \) : number of additional machines
\( CT \) : actual cycle time
\( BP \) : number of bundle progressive

### 3.2. Objective Function of Model

The objective of the model is to minimize the total cost of assembly line by summing the operation costs, cost of machine, cost for additional capacity, costs of idle capacity, and cost of outsourcing.

\[
\text{Min } Z = B^{opr} + B^{mc} + B^{kps} + B^{idle} + B^{out}
\]

### 3.2.1. Operation Cost \((B^{opr})\)

This cost is the product of the actual cycle time \((CT)\) with optimal quantity of production \((Q)\) and the cycle time cost \((a)\) and the period of demand \((T)\).

\[
B^{opr} = (CT \times Q \times T \times a)
\]

The actual cycle time is the division between the processing time of each task with the machine for each task needs to meet the optimal Q. Number of progressive bundle \((BP)\) is the division between the cycle
time predetermined by the actual cycle time, with a view to determine how many components that must be provided in a single bundle (batch)

\[ CT_i = \frac{st_i}{mc_i}, \quad \forall i \in I \]  

(3)

\[ CT_i < \frac{P}{Q}, \quad \forall i \in I \]  

(4)

\[ CT = \text{Max } CT_i \quad \forall i \in I \]  

(5)

\[ BP = \text{Cyc } / CT \]  

(6)

3.2.2. *Cost of Machine (B*\textsubscript{Mc}*)

Cost of machine is:

\[ B_{Mc} = (JM \times T \times b) \]

(7)

Time required for completing number of orders \( Q \) for each task

\[ s_i = Q \times st_i \quad \forall i \in I \]  

(8)

Remaining times for each task or operation unmet by installed capacity at previous period to meet number of order \( Q \)

\[ sp_i = \begin{cases} s_i - m_i^P, & s_i > m_i^P \\ 0, & \text{else, } \forall i \in I \end{cases} \]  

(9)

Number of machine required for each task to met number of order \( Q \).

\[ mc_i = m_i^P + \frac{sp_i}{P}, \quad \forall i \in I \]  

(10)

\[ mc_i \in \text{integer} \quad \forall i \in I \]  

(11)

\[ JM = \sum_{i=1}^{I} mc_i \]  

(12)

3.2.3. *Cost for additional capacity (B*\textsubscript{Min}*)

The cost for additional capacity is a multiplication of the number of additional machine (\( MB \)) and the additional machine cost (\( c \))

\[ B_{Min} = c (MB) \]  

(13)

\[ md_i = mc_i \times m_i, \quad \forall i \in I \]  

(14)

\[ MB = \sum_{i=1}^{I} md_i \]  

(15)

3.2.4. *Cost for idle capacity (B*\textsubscript{idle}*)

This cost is obtained by multiplying the total number of idle machines on every period (\( ID_t \)) which represents the difference between available machine (actual machine) with machines required in each period of demand in the planning period with the cost of capacity (\( d \)).
\[ B_{idle} = \sum_{t=1}^{T} ID_t \] (16)

Time for task \( i \) required to meet demand at period \( t \).
\[ s_{it} = D_t s_{t_i}, \quad \forall i \in I, \forall t \in T \] (17)

Number of machine for each task at demand period \( t \).
\[ mc_{it} = \frac{s_{it}}{P}, \quad \forall i \in I, \forall t \in T \] (18)

\[ mc_{it} \in \text{integer}, \quad \forall i \in I, \forall t \in T \] (19)

\[ JM_t = \sum_{i=1}^{I} mc_{it}, \quad \forall t \in T \] (20)

Number of idle machine at each period.
\[ ID_t = \begin{cases} JM - JM_t, & JM > JM_t \\ 0, & \text{lainnya, } \forall t \in T \end{cases} \] (21)

3.2.5. Outsourcing Cost (\( B_{out} \))
This outsourcing costs arising from capacity provided cannot meet the demand on each period consisting of sewing costs and transportation costs. The cost of sewing is a multiplication of the number of products outsourced times the sewing outsourcing costs. The costs are affected by discounts amounting to 10% of each quantity of product in the outsourcing of more than 1000 pieces. Transportation costs are multiplication of the number of shipments with transport costs.
\[ B_{out} = \sum_{t=1}^{T} (e O_t + f TR_t ) \] (22)

Number of orders outsourced at period \( t \).
\[ O_t = \begin{cases} D_t - Q, & D_t > Q, \\ 0, & \text{else, } \forall t \in T \end{cases} \] (23)

Transportation for delivery of products each period.
\[ TR_t = \begin{cases} 0, & O_t = 0, \\ 1, & \text{else, } \forall t \in T \end{cases} \] (24)

3.2.6. Constraints
a. Operation \( i \) assigned on a work station \( k \), and applies to all operations \( i \).
\[ \sum_{k=1}^{K} X_{ik} = 1, \quad \forall i \in I \] (25)

b. Precedence constraints
\[ \sum_{k=1}^{K} kX_{wk} - \sum_{k=1}^{K} kX_{vk} \geq 0, \quad \forall (v, w) \in \text{Pred} \] (26)

c. The total processing time of each operation at each station does not exceed the cycle time and applicable to all stations \( k \).
\[
\sum_{i=1}^{I} st_i X_{ik} \leq CT, \quad \forall k \in K \tag{27}
\]
d. Total placements of each operation at each station does not exceed the number of work stations and applies to all \( i \) operations.
\[
\sum_{i=1}^{I} k X_{ik} < ws, \quad \forall i \in I \tag{28}
\]
e. Number of machine in assembly line do not exceed space available \( JM_{max} \)
\[
JM \leq JM_{max} \tag{29}
\]
f. Maximum number of outsourcing.
\[
\sum_{t=1}^{T} O_t \leq O_{\text{max}}, \quad \forall t \in T \tag{30}
\]
g. Quantity Discount
\[
f = \begin{cases} 
20, & O_t < 1000, \\
18, & \text{else}, \; \forall t \in T 
\end{cases} \tag{31}
\]
h. Binary integer.
\[
X_{ik} \in \{0, 1\}, \quad \forall i \in I, \forall k \in K \tag{32}
\]
\[
JM \in \text{integer} \tag{33}
\]

4. Solution method and numerical examples
The model here is solved using branch and bound techniques using the Lingo 11. For numerical example, data from Samadhi and Totong [4] are used where the product is a short pant with precedence diagram as seen on Figure 1 and the assembly operation data as shown in Table 1. A set of parameter used in Samadhi and Totong is also used and since this new model considered outsourcing, the result is better than the previous one as the previous model considered the lost sale.

Table 1. Assembly Operation Description [4]

| No | Operation Name          | Machine Name          | Operation description                | Code | Operation Time (min) |
|----|-------------------------|-----------------------|--------------------------------------|------|----------------------|
| A  | Left Sewing             | Juki DDL 5550–6       | Single needle lock stitch            | J1   | 0.729                |
| B  | Right Sewing            | Juki DDL 5550–3       | Single needle lock stitch            | J1   | 0.511                |
| C  | Sew buttonholes         | Juki 780              | Simple automatics machine            | J2   | 0.170                |
| D  | Connect Left- Right (L+R)| Juki DDL 5550–3      | Single needle locks stitch           | J1   | 1.096                |
| E  | Sew button              | Juki LK 1851          | Simple automatics machine            | J2   | 0.167                |
| F  | Bartack                 | Juki 1850             | Simple automatics machine            | J2   | 0.173                |
| G  | Sewing back             | Juki MS 1190          | Feed off the arm                     | J3   | 0.351                |
| H  | Sew out seam            | Juki MS 191           | Feed off the arm                     | J3   | 0.360                |
| I  | Sew inseam              | Juki MS 1190          | Feed off the arm                     | J3   | 0.349                |
| J  | Sew leg Opening         | Brother DDL SL 737    | Single needle lock stitch            | Brother | 0.924          |
| K  | Stitch care label       | Juki DDL 5550–6       | Single needle lock stitch            | J1   | 0.363                |
| L  | Elastic Mounting        | Yamato VC 2840P-254-X02D | Over deck elastic machine          | Yamato  | 0.888                |
| M  | Stitch care label       | Juki DDL–8700–7       | Single needle lock stitch            | J1   | 0.333                |
| N  | Sew main label          | Juki DDL 5550-3       | Single needle lock stitch            | J1   | 0.533                |
For numerical example of the model a set of parameter as seen on Table 2 is used. As this model purpose for re-balancing the existing line, the number of work station and available machine on each work station is used as an input as shown in Table 3. The demand for 22 periods as the input is shown in Table 4.

Table 2. Model Parameters

| Parameter symbol | Description               | Value          |
|------------------|---------------------------|----------------|
| P                | Production time per day   | 420 minutes    |
| a                | Assembly cost             | 10,000         |
| b                | Cost of the machine       | 80,000         |
| c                | Workstation installation cost | 500,000     |
| d                | Lost sale cost per unit   | 30,000         |
| e                | Cost of idle machine      | 300,000        |
| CT               | Cycle Time                | 2 minutes      |

Table 3. Number of Available Machines

| Task (i) | Number of Machines (m_i) |
|----------|--------------------------|
| A        | 4                        |
| B        | 3                        |
| C        | 1                        |
| D        | 7                        |
| E        | 1                        |
| F        | 1                        |
| G        | 2                        |
| H        | 2                        |
| I        | 2                        |
| J        | 6                        |
| K        | 2                        |
| L        | 5                        |
| M        | 2                        |
| N        | 3                        |

The solution for this example result in the number of machine utilised for meeting demand is remain 41 machines. The demand fluctuations is met by using the outsourcing and the number of outsourcing is depicted in table 5, where during this outsourcing periods, the number of production from the line is 2305 pieces.
Table 4. Data for Demand

| Period | Demand (pcs) | Period | Demand (pcs) |
|--------|--------------|--------|--------------|
| 1      | 2100         | 12     | 2690         |
| 2      | 3150         | 13     | 2100         |
| 3      | 3800         | 14     | 800          |
| 4      | 950          | 15     | 1600         |
| 5      | 700          | 16     | 950          |
| 6      | 2600         | 17     | 2100         |
| 7      | 1860         | 18     | 2680         |
| 8      | 800          | 19     | 1860         |
| 9      | 650          | 20     | 2700         |
| 10     | 2400         | 21     | 2490         |
| 11     | 2600         | 22     | 2580         |

Table 5. Quantity of outsourcing

| Period | Outsourcing Quantity (pcs) | Period | Outsourcing Quantity (pcs) |
|--------|----------------------------|--------|-----------------------------|
| 1      | 0                          | 12     | 385                         |
| 2      | 845                        | 13     | 0                           |
| 3      | 1495                       | 14     | 0                           |
| 4      | 0                          | 15     | 0                           |
| 5      | 0                          | 16     | 0                           |
| 6      | 295                        | 17     | 0                           |
| 7      | 0                          | 18     | 375                         |
| 8      | 0                          | 19     | 0                           |
| 9      | 0                          | 20     | 395                         |
| 10     | 95                         | 21     | 185                         |
| 11     | 295                        | 22     | 275                         |

Analysis is performed by looking at the effect of an increase in average demand for change in the number of additional machine. The average demand increased by 10%, 20%, 30%, 40%, 50%, 60%. And the result as shown in Figure 2 indicates that the additional number of machines will finally steady at the maximum of available space of the assembly line, at the number of 76 machines. Accordingly the total cost of assembly line is increased, due to the increased number of machines and outsourcing.
5. Concluding Remarks
The model developed is able to answer the problem of fluctuations in demand in the garment industry by determine the decision to add capacity and outsourcing to get the minimal total cost of the assembly line. An average increase in demand will affect the total cost of the assembly line and other expenses except the cost of operation. This capacity expansion occurred to the average increase in demand of 60%, and further increased will not add the number of machine due to limitation of space in the line. In this regard, the increased average demand is met by increased in the number of outsourcing.

This model is developed for a single product, thus a further development to include the mixed product in one line is necessary.

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