A MATHEMATICAL MODEL FOR ASSEMBLY LINE BALANCING PROBLEM WITH LEAN MANUFACTURING

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Abstract

The line balancing problem is a combinatorial optimization problem and it is in NP-complete class. The line balancing is important to improve quality and to reduce transaction costs in the textile and apparel industry. Line balancing is defined as assigning operations to work stations according to the operation flexibilities. Lean manufacturing eliminates the need of stocking and targets to manufacture low-cost high-quality.

In this paper, a 0-1 integer mathematical model has been created for the assembly line balancing problem with lean manufacturing techniques. This model allows that each operation is optimally balanced using precedences of the operation in the assembly line balancing problem with lean manufacturing.

Keywords: line balancing, lean manufacturing, mathematical modeling, boolean programming.

Introduction

Assembly lines are flow oriented production systems which are still typical in the industrial production of high quantity standardized commodities and even gain importance in low volume production of customized products. Among the decision problems which arise in managing such systems, assembly line balancing problems are important tasks in medium-term production planning. Assembly lines were originally developed for a cost efficient mass production of standardized products, designed to exploit a high specialization of labour and the associated learning effects [2].

The operations are consecutively launched down the line and are moved from work station to work station. At each work station, certain operations are repeatedly performed regarding the cycle time. The decision problem of optimally balancing the assembly work among the work stations with respect to some objective is known as the assembly line balancing problem.

Manufacturing a product on an assembly line requires partitioning the total amount of work into a set of elementary operations named operations $V = \{1, . . . ,n\}$. Performing a operation j takes an operation time tj and requires certain equipment of machines and/or skills of workers (operators). Due to technological and organizational conditions precedence constraints between the tasks have to be observed [1].

Under the term assembly line balancing, various optimization models have been introduced and discussed in the literature which aim at supporting the decision maker in configuring efficient assembly systems. Since the first mathematical formalization of assembly line balancing by Salveson in 1955 [3], academic work mainly focused on the core problem of the configuration, which is the assignment of tasks to stations. Subsequent works however, more and more attempted to extend the problem by integrating practice relevant constraints, like U shaped lines, parallel stations or processing alternatives [1, 2, 4].

Lean manufacturing is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Main strategy of the lean manufacturing is to improve quality, cost and delivery performance while reducing the flow time. Lean manufacturing eliminates the need to keep stocks and aims to enable the low-cost and high-quality production [8].

Mathematical Formulation

We use the formulation of the Bin Packing Problem (BPP) [5] to construct mathematical model of line balancing problem with lean manufacturing. The Bin Packing Problem can be described as follows [5]. Given *n* items and *n* bins. Assign each item to one bin so that the total weight of the items in each bin does not exceed c and the number of bins used is a minimum. We will use operators instead of bins, operations instead of items and standard times instead of item weights in the assembly line balancing problem.

In the assembly line balancing problem, we have n operators and n operations (Figure 1 and Figure 2). All operators have the same work time per a day as c. Nevertheless, some operations in the line can have some precedences. For example, if operation *j* has a relation as $s_j \prec j \prec o_j$, then operation *j* has flexibility between operation s_j and operation o_j [6, 7].

We know that the BPP is in NP-complete class. It is easy to see that the line balancing problem can be reduced the BPP in polynomial time as above. So, the line balancing problem is in NP-complete class.

The goal of the model is to find an operation assignment to operators with minimum work time under the operation precedences. This is the same to find the minimum number of operators who will be worked in all operations.

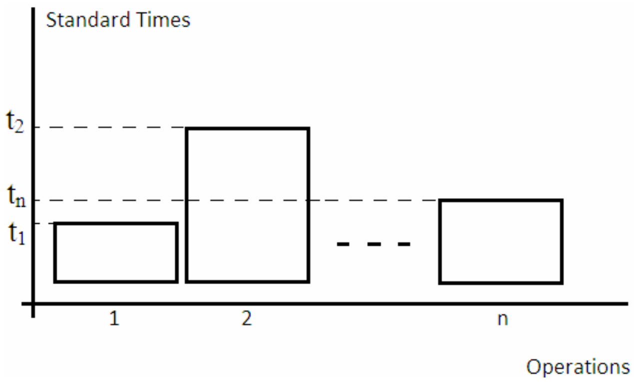

Figure 1- Operations and their standard times as seconds

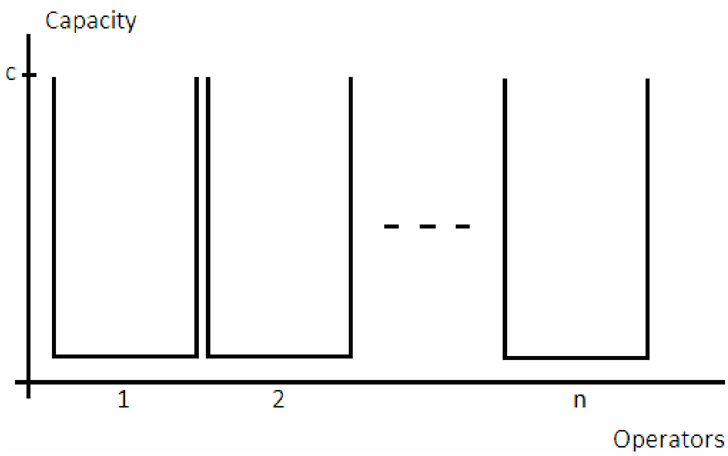

Figure 2- Operators and their work time bound (c)

Input parameters:

t_j : Standard time of operation j (second)

s_j : An operation that starts flexibility of operation *j*

o_j : An operation that breaks up flexibility of operation *j*

c : Work time per a day of one operator (minute)
p : Production quantity
n : Number of operations and number of operators
$i, j = 1,...,n$

Decision variables:

$$y_i = \begin{cases} 1 & ,if\ \ operator\ i\ is\ used, \\ 0 & ,otherwise, \end{cases} \qquad i = \overline{1,n}$$

$$x_{ij} = \begin{cases} 1 & ,if\ \ operation\ \ j\ \ is\ \ assigned\ \ to\ \ operator\ \ i, \\ 0 & ,otherwise. \end{cases} \qquad i, j = \overline{1,n}$$

Following is the 0-1 integer mathematical model of the assembly line balancing problem with lean production:

$$\sum_{i=1}^{n} y_i \to Min \tag{1}$$

$$\sum_{j=1}^{n} p \cdot t_j \cdot x_{ij} \le c \cdot y_i, \qquad i = \overline{1,n}, \tag{2}$$

$$\sum_{i=1}^{n} x_{ij} = 1, \qquad j = \overline{1,n}, \tag{3}$$

$$i \cdot x_{ij} - k \cdot x_{k s_j} \ge 0, \qquad i, j, k = \overline{1,n}, \tag{4}$$

$$k \cdot x_{k o_j} - i \cdot x_{ij} \ge 0, \qquad i, j, k = \overline{1,n}, \tag{5}$$

$$x_{ij} = 0 \vee 1, \qquad i, j = \overline{1,n}, \tag{6}$$

$$y_i = 0 \vee 1, \qquad i = \overline{1,n}, \tag{7}$$

Equation (1) minimizes the number of operators used. Constraint (2) ensures that the sum of operations times which are assigned to operator *i* cannot exceed the work time per a day of one operator. Constraint (3) guarantees that each operation can be assigned to one operator at most. Constraint (4) and (5) ensure that operation *j* cannot be performed before operation s_j and after operation o_j.

Conclusion

In this study, line balancing problem, which is important to improve quality and to reduce transaction costs in the textile and apparel industry, is considered. In this paper, a 0-1 integer mathematical model was constructed to line balancing problem with lean manufacturing techniques in textile and apparel industry. The goal of this model is to find optimum operation distribution to operators in the line balancing problem using given operation precedences. This model can also be used to balance various production lines which contain different operations.

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