A simulation-based approach for solving assembly line balancing problem

Xiaoyu Wu
College of Mechanical Engineering, Donghua University, Shanghai 201620, China
1036166372@qq.com

Abstract. Assembly line balancing problem is directly related to the production efficiency, since the last century, the problem of assembly line balancing was discussed and still a lot of people are studying on this topic. In this paper, the problem of assembly line is studied by establishing the mathematical model and simulation. Firstly, the model of determining the smallest production beat under certain work station number is anysized. Based on this model, the exponential smoothing approach is applied to improve the algorithm efficiency. After the above basic work, the gas stirling engine assembly line balancing problem is discussed as a case study. Both two algorithms are implemented using the Lingo programming environment and the simulation results demonstrate the validity of the new methods.

1 Introduction
The assembly line is composed of a series of continuous workstations, and the important issue that needs to be considered in establishing and applying the assembly line is the rational allocation of the workstations under given constraints. When multiple workstations are connected as an assembly line, if the production time of each workstation is not evenly distributed, this will lead to the production of the assembly line for the longest production time of the workstation, so there will be bottlenecks and other phenomena.

To balance the assembly line, the first and foremost task is to improve the production efficiency, to increase the profits of enterprises, and to reduce the production cycle; Secondly, the balanced assembly line can improve product quality. If the assembly line is not at a good balanced State, it may lead to the surplus of workload by the staffs or equipments, which may not only lead to the decline of product quality, thus exacerbating the burden on employees or equipment. Assembly line balance can also reduce inventory. Upon the axiom of rational allocation of working flows regarding the process of production, unnecessary sections can be reduced to as least as possible.

The study toward the balance of assembly line was brought out by Helgeson. Following his scholarship, A linear programming model proposed by Salveson for assembly line balance was proposed in 1955, after which many methods were devised to solve the assembly line balance (ALB) problem. The study of the ALB problem can be divided into the study of the approximate solution and the exact solution. The mathematical model and method for the specific solution to the ALB problem are sorted out by Baybar. However, as ALB problem is a typical NP-hard problem, heuristic algorithm is therefore the most popular for solving it by finding the approximate optimal solution with the fastest
time. By Ghosh and Gagnon, academic studies on the assembly line design, uniformity, production were sorted out and compiled.

For the issues upon the balance of assembly line, the heuristic algorithm calculating the number of workstations in the case of known production rhythms is studied. Rules with the highest number of jobs in the workstations (MAXimum DURI time: MAX-DUR), and the maximum number of follow-up jobs (MAXimum Total number of FOLlower tasks: MAX-TFOL), the MAX maximum number of immediate follower task (MAX-IFOL rules), and the maximum rank position weight (MAX-RPW) rule were proposed regarding the approximate solutions. Arcus proposes a method of selecting the optimal assignment by combining the above rules. Hoffmann invented the heuristic algorithm by using an array of precedence matrices, and Gehrlein and Patterson modified the Hoffmann algorithm to shorten the computation time.

In this paper, the balance of the assembly line is studied with the assembly line of the gas stirling engine. The biggest advantage of gas stirling engine is the ability to use a variety of energy, and environmental protection and other advantages, but it is still in a small batch of manual assembly mode. So by improving the assembly line balance problem the gas heat engine production efficiency can be improved to meet the needs of the market.

2 Problem Description
The mixed-flow assembly line is the way in which multiple products with similarity are produced on the same assembly line. Due to different models of its production and production content, production time differences, the production of varied products have led to problems on the reduction of time switching between the various models of work.

The flow of mixed-flow assembly line is shown in Figure 1. The overlapping processes from various models of work are re-compiled together for a new work flow graph.

![Figure 1. The flow of mixed-flow assembly line](image)

In this paper, two main issues of SALB will be discussed, briefly, (1) to find the smallest production beat; (2) to find the minimum smoothing index. The two will be discussed in detail as follows:

(1) Type-1 ALB Problem: Minimization of production beat
The Type-1 ALB problem is the number of fixed workstations that minimizes the production tempo. This issue is also the focus of the ALB issue. Reduce production rhythm to increase production speed and thus increase production. The traditional ALB problem focuses the number of workstations in the assembly line assembly phase. The Type-1 ALB problem aims at improving productivity when the workstation has been identified.
(2) Type-2 ALB Problem: Minimization of smoothness index
The Type-2 ALB problem focuses on minimizing the smoothness of the workstations when the workstation has been identified. The production time is reduced by distributing the processes evenly to the workstations. The process allocation is closely related to the beat time.

3 Mathematical Model

3.1 Type-1 ALB problem
This type of problem is the mathematical model established to find the minimum production rhythm. After the installation of the assembly system, the number of work orders is determined. It is a more balanced solution toward the priorly optimized model, the mathematical model is as follows:

\[ \text{min} Z = C \]  \hspace{1cm} (1)

S.T.

\[ \sum_{k=1}^{K} X_{ik} = 1 \quad \forall i \in I \]  \hspace{1cm} (2)

\[ \sum_{i=1}^{m} X_{ik} \cdot t_i \leq C \quad \forall k \in K \]  \hspace{1cm} (3)

\[ \sum_{k=1}^{K} \left( KX_{jk} - KX_{ik} \right) \geq 0 \quad \forall (i,j) \in \text{Pred} \]  \hspace{1cm} (4)

To be specified:
C - assembly line beats time;
K - number of stations
k - the row number of the station, such as \( k = 1, 2, \ldots, k \);
M - number of operating units;
I - the i-th operation;
J - j job
\( X_{ik} \) - it is set to 1 when the i-th job is assigned to station K;
\( X_{jk} \) - it is set to 1 when the j-th job is assigned to station K;
\( A_k \) - the kth station is 1 for use, otherwise 0;
\( t_i \) - the operation time of the i-th operation;
Pred - A collection of job element sequences that represent the context of the job element.

3.2 Type-2 ALB problem
The new introduced Minimum smooth exponential model is as follows:

\[ \text{min} = \sqrt{\frac{\sum_{k=1}^{K} \left( C - t_i \right)^2}{K}} \]  \hspace{1cm} (5)

S.T.

\[ \sum_{k=1}^{K} X_{ik} = 1 \quad \forall i \in I \]  \hspace{1cm} (6)

\[ \sum_{i=1}^{m} X_{ik} \cdot t_i \leq C \quad \forall k \in K \]  \hspace{1cm} (7)

\[ \sum_{k=1}^{K} \left( KX_{jk} - KX_{ik} \right) \geq 0 \quad \forall (i,j) \in \text{Pred} \]  \hspace{1cm} (8)

To be specified:
C - assembly line beats time;
K - number of stations
k - the row number of the station, such as \( k = 1, 2, \ldots, k \);
M - number of operating units;
I - the i-th operation;
J - j job
\( X_{ik} \) - it is set to 1 when the i-th job is assigned to station K;
\( X_{jk} \) - it is set to 1 when the j-th job is assigned to station K;
\( A_k \) - the kth station is 1 for use, otherwise 0;
\( t_i \) - the operation time of the i-th operation;
Pred - A collection of job element sequences that represent the context of the job element.
3.3 Solution method for the model

The mathematical model software used in this paper is Lingo, which is an object-oriented scripting language. The above mathematical model is implemented in Lingo as follows:

Figure 2 Data for the Lingo minimum smoothing index

Figure 2 is the gas stirling engine e data input and programming, set the assembly line and the order of the order between the order, the order relationship can be sorted through the priority map, and enter the total number of processes to obtain the minimum smooth index.

Figure 3 Lingo minimum smoothing index conditions

The first @FOR represents the formula (6), indicating the order of the order between the order, that is, only in the previous process to complete the basis of the next step; the second @ FOR said formula (8), is also displayed (7), indicating that the work time of each station can not exceed the production of the beat time, which is a single production line balance can not violate the conditions; finally obtained is the minimum smoothing Index, using @BIN to represent 0,1 relationship, the end of programming.

The following pre-set assembly line number of 7,8,9 units, and through the above smoothing index algorithm to optimize. The algorithm works as follows:
From the above results we can see that the smoothing index is the largest when the number of stations is 7, the smallest at 9:00. Likewise, the production tact time is the smallest when the number of stations is 9. This shows that when the number of stations is 9, the production of the beat time is 96min when the gas heat engine production efficiency to achieve the highest.

4 Summary and future work

In this paper, the method of balancing the assembly line of the gas stirling engine is studied, and the mathematical model of the minimum production rhythm and the minimum number of stations under the production rhythm is listed. By introducing the algorithm of smoothing index, Combined with one, reducing the trouble of two calculations, and can be obtained through the smooth index to directly see the best efficiency of the balance of the program, so that the beat time, the number of stations and smoothing index once completed.

Assembly line balance problem Because it is a very complex problem, not only need to produce the beat time and the minimum number of stations, the layout of the entire assembly line also affected the assembly line production efficiency. So in the beat time and the number of stations on the basis of the assembly line to optimize the layout to improve production efficiency.

References

[1] Pine, B. J., B. Victor, and Andrew C. Boyton (1993), “Making Mass Customization Work,” Harvard Business Review, 71, 108–122.
[2] Pine, B. J., B. Victor, and Andrew C. Boyton (1993), “Making Mass Customization Work,” Harvard Business Review, 71, 108–122.
[3] I.Sabuncuoglu, E.Erel and M.Tanyer, Assembly line balancing using genetic algorithms, Journal of Intelligent Manufacturing. 2000, Vol. 11:295-310.
[4] Simaria A S, Vilarinho P M. A genetic algorithm based approach to mixed-model assembly line balancing problem of type II[J]. Computers and Industrial Engineering,2004,47(4): 391-407.
[5] Kotha, S. (1996). From mass production to mass customization : the case of the National Industrial Bicycle Company of Japan, European Management Journal, 14(5), 442-450.
[6] Jing, Y., Changsong, M. (2014). Flexsim Logistics System Modeling and Simulation Metallurgical Industry Press.
[7] Xiaoping, Z.(2006). System simulation software Flexsim3.0 practical tutorial. Tsinghua University Press.
[8] Hongwei, Z. (2005). LINGO 8.0 and its application in environmental system optimization. Tianjin University Press.
[9] Huaming, S. (1999). One type of assembly line balance algorithm [D]. Nanjing University of Science and Technology.
[10] Zhuo, L. (2007). Research and Development of Assembly Line Balancing System [A]. Industrial Engineering.
[11] Yunpu, D. (2003). Study on the balance of assembly line [J].
[12] Shanping, H., Lifeng, X. (2005). Research on Balance Method of Engine Assembly Line.
[13] Han, Y., Yabo, L. (2007). Simulation and Optimization of Industrial Process Based on Flexsim [J]. Journal of Hubei University of Technology.
[14] Xiaoyan, W. (2007). Assembly line production balance [D]. Shanghai Jiaotong University.