# Mixed Flow Assembly Line Balancing Problem Considering Material Supply Strategy

Zhou Yujia<sup>1</sup>, Shen Jin<sup>2</sup>, Bin Wu<sup>2</sup>, and Chang Daofang<sup>1</sup>

<sup>1</sup>Institute of Logistics Science and Engineering, Shanghai Maritime University, China <sup>2</sup>School of Business, Shanghai Dianji University, China Email: 1778453803@qq.com, shenjin2002@sina.com, wub@sdju.edu.cn, changdaofang@126.com

Abstract—With the capacity limitation of the assembly line buffer area, a method for solving the mixed flow assembly line balancing problem considering material supply strategy is proposed. This paper analyzes the changes in material transportation time and assembly time due to different supply strategies, and proposes a method for jointly modeling the assembly line balancing and material supply problem. In the case of meeting the production cycle, with the buffer area capacity as the limit and the shortest production operation time as the goal, a joint optimization model including material handling time, material transportation time and assembly line working time is established, and the model is designed for the established model Genetic algorithm with piecewise coding. Finally, the proposed algorithm was evaluated using a workshop raw date, the simulation results show that although the indirect supply cost is relatively more than the direct supply, it can effectively alleviate the problem of the capacity limitation of the buffer area.

*Index Terms*—Assembly line balance, material supply strategy, direct supply, indirect supply, capacity limitation, piecewise coding

# I. INTRODUCTION

An assembly line refers to an assembly line that mixes and assembles different types of products with similar structures and processes in one production line [1]. Its assembly line balance plan is related to whether the enterprise can give full play to its economic and social benefits. Therefore, designing a reasonable assembly line balance plan is particularly important for the production and operation of the enterprise.

Because of its importance and complexity, the assembly line balance problem has received extensive attention and research from many scholars. Its research content is mainly divided into consideration of certain specific factors (such as assembly line labor costs [2], demand fluctuations [3]), in order to minimize the number of workstations, the minimum production cycle, etc. as Target problem modeling, focusing on model solving algorithms (such as improved genetic algorithms, simulated annealing algorithms) and several other types of research. However, in actual production, the limitation of the line-side buffer space and the material transportation methods are different, which may cause the

original minimum beat balance scheme to be changed due to the influence of the buffer space or the transportation method. Therefore, it is assumed that the material is not limited by the buffer space, and the model of the irrelevant material supply strategy has certain limitations in reflecting the actual situation.

This paper proposes a mixed-flow assembly line design method that considers the material supply strategy. Under the constraints of line-side buffer space, the packaging method of the material supply strategy in the assembly shop is analyzed. The transport time calculation model seeks the optimal allocation plan and supply strategy for each job, and takes the plan with the shortest production and transport time as the optimal solution.

The rest of the paper is arranged as follows. The second chapter analyzes the current status of domestic and foreign research, and the third chapter describes and analyzes the problems raised in this article; the fourth chapter builds the model; the fifth chapter briefly introduces segmented coding; the sixth chapter conducts experimental calculation and analysis; the last chapter summarizes

# II. LITERATURE REVIEW

In 2015, Johannes [4] for the first time jointly modeled two relatively independent problems of assembly line balance and material supply, and optimized it with the goal of minimizing production costs. However, the model still considers the balance of simple assembly lines, namely the first type, is not suitable for the mainstream mixed production mode. Daria Battini [5] analyzed and summarized the three material supply methods of direct supply, indirect supply and cyclic supply from the perspective of economics, summed up the advantages and disadvantages of the three methods, and minimized the operation time of the assembly line. Amir Nour [6] considered an assembly line balance and parts supply costs, and designed an integrated mathematical model that can simultaneously determine the optimal number of workstations and the optimal number of supermarkets. Li Wei [7], Yi Jianyang [8], Wu Yongming [9] Although the material supply problem is considered in the assembly line balance problem, it is essentially a phased modeling of the two problems without considering the material supply impact of the problem on the assembly line balancing scheme.

Manuscript received July 5, 2021; revised October 28, 2021.

# III. PROBLEM STATEMENT

# A. Problem Description

There are several job elements assigned to the workstation according to the job priority order (see Fig. 1). The production materials corresponding to each job element are transported by the material transport vehicle from the warehouse to the assembly line according to different supply strategies, and the line-side buffer area is placed to supply production consumption and maintain the smooth operation of the assembly line is to minimize production and transportation time. This is a multi-variety, small-batch production method with a selectable supply strategy. The layout of the workshop corresponding to this problem is shown in Fig. 2. The distance from the warehouse to the assembly line is L.



Figure 1. Job priority.



Figure 2. Assembly line workshop layout.

Considering the material pick-up time of the staff in the station, the same parts are i, j, and q. The direct walking time of the workers is t1+t2+t3, and the walking time of the indirect workers is t1+t2. The difference in walking time between workers due to different supply methods is  $\Delta t_i^{H,Line}$ . (See Fig. 3).



Figure 3. Worker pick-up method.

## B. Analysis of Material Supply Strategy

Direct supply is described as: the forklift is responsible for transporting containers containing the same parts (hereinafter referred to as homogeneous containers, as shown in Fig. 4) directly from the warehouse to the assembly line.



Figure 4. Homogeneous container parts packing method.

Indirect supply can be described as: the forklift is responsible for transporting containers with the same parts to the RDC area (Regional Distribution Center) for selection, mixing and packing, and then containers with multiple parts (hereinafter referred to as mixing Container) to the production line. (See Fig. 5)



Figure 5. Mixed container parts packing method

In order to make full use of the buffer space of the assembly line and reduce the frequency of material distribution, indirect supply has become a necessary supply strategy in the transportation process because of the large number of parts in the shipping container and the small storage space. And direct supply, because it is directly transported from the warehouse to the line without going through the RDC area, greatly saves vehicle transportation time. The authors analyze the differences between the two supply methods in terms of transportation distance and transportation time, as shown in Table I.

TABLE I. COMPARISON OF SUPPLY POLICY

Supply policy	transport vehicle	handling time	Picking time
Direct supply	forklift	0	$\Delta t_i^{H,Line}$
Indirect supply	forklift+ tow track	$t_i^{E,AM}$	0

Assuming that the parts corresponding to operation i are brought online by indirect supply, its transportation time mainly consists of three parts: the transportation time of the forklift from the RDC area to the assembly line ( $\Delta T_1$ ), the transportation time of the trailer ( $\Delta T_2$ ) Material handling time in the RDC area ( $\Delta T_3$ ).

Where  $\Delta T_1 = -\sum_{\forall ik} v_{ik} \frac{b_i \times \Delta t^{T,P}}{\eta_i^P}$  depends on the time

 $\Delta t^{T,P}$  required for each trip of the forklift, the number of parts  $\eta_i^P$  that can be accommodated in each ordinary

container, and the average assembly rate  $b_i$  of the operation. In each transport of the trailer with time  $t^{T,MC}$ , the mixed container of  $\eta^{MC1}$  orders  $\eta^{MC2} \cdot \rho$  can be carried, and the transport time of the trailer is H. In addition, the manual transport time  $\Delta T_2 = \sum_{\forall k} z_k \frac{t^{T,MC}}{\eta^{MC1} \eta^{MC2} \rho}$  in the RDC

area depends on the size of the part and the process efficiency, and the workers do not affect each other.

# IV. MATHATHEMATICAL MODEL

#### A. Objective Function

$$\min f = \max(\sum_{m=1}^{M} r_m \times T_{mk}) + \Delta T$$
(1)

#### B. Restrictions

While seeking to optimize the balance of the mixedflow assembly line, it is necessary to meet the principles of non-overlapping operating units, minimizing the beat, and operating priorities. For ease of description and understanding, the following variables are first defined:

$$x_{ik} = \begin{cases} 1, & \text{Job i is assigned to k workstation} \\ 0, & \text{else} \end{cases}$$
(2)

$$v_{ik} = \begin{cases} 1, \text{ Job i is assigned to workstation k and use indirect supply} \\ 0, \text{ else} \end{cases}$$
(3)

$$Z_{k} = \left\{ \begin{array}{ll} 1, & \text{Mixing container placed on k workstation} \\ 0, & \text{else} \end{array} \right\} (4)$$

Further, the constraint conditions of the mixed-flow assembly line equilibrium model considering the material supply strategy are expressed as follows:

$$\sum_{k=1}^{K} x_{ik} = 1, i = 1, 2, \dots n$$
(5)

$$\sum_{k=1}^{K} kx_{ik} \leq \sum_{k=1}^{K} kx_{jk}, \forall (i, j) \in Pset$$
(6)

$$\sum_{\forall ik} \left( (a_i^z + a_i^E) x_{ik} - a_i^z v_{ik} \right) \le A - \sum_{\forall k} z_k A^{MC}$$
(7)

Equation (5) to (7) are constraint schemes for the production balance design of mixed-flow assembly lines, where equation (5) guarantees that one job element is allocated to one and can only be in one workstation; equation (6) indicates that All (direct) antecedent elements are assigned to the workstation before this job element can be assigned; Equation (7) indicates that the capacity occupied by all parts does not exceed the space capacity of the buffer area itself.

$$v_{ik} \le x_{ik}, \forall i, k \tag{8}$$

$$\sum_{\forall k} z_k \le 1, \forall k \tag{9}$$

$$T_{mk} = \sum_{m=1}^{M} \sum_{\forall i} ((t_{mi} + \Delta t_i^{H,Line}) x_{ik} - v_{ik} \Delta t_i^{H,Line}) (10)$$

Equation (8) assigns constraints to the supply policy, indicating that each workstation will be scheduled to work, but not each workstation cache area will have a hybrid container; Equation (9) represents a workstation cache area with a maximum of one hybrid container; Equation (10) Represents the working time of the m-th model product on the k-th workstation;

$$\Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3 \tag{11}$$

$$\Delta T_1 = -\sum_{\forall ik} v_{ik} \frac{b_i \times \Delta t^{T,P}}{\eta_i^P}$$
(12)

$$\Delta T_2 = \sum_{\forall k} z_k \frac{t^{T,MC}}{\eta^{MC1} \eta^{MC2} \rho}$$
(13)

$$\Delta T_3 = \sum_{\forall ik} v_{ik} t_i^{E,AM} \tag{14}$$

Equations (12) to (14) indicate the calculation of vehicle transportation time for each car order, where equation (12) indicates that the forklift saves transportation time from the RDC area to the assembly line due to the indirect supply; equation (13) indicates the trailer Time for transporting mixed containers; Equation (14) represents additional manual handling time in the RDC area.

#### V. PIECEWISE CODING GENETIC ALGORITHM

The assembly line balancing problem with material supply strategy proposed in this paper is a typical NP-hard problem. The solution of this balance scheme is not only related to the priority of the job, but also affected by the material supply strategy and the buffer capacity limit, which makes the solution more difficult. Genetic algorithm (GA) has strong global search ability, high solution accuracy and less calculation time. In order to better solve the problem of this paper, a piecewise coding method is proposed to represent the genetic algorithm of assembly line balance scheme.

In this paper, the genetic algorithm coding idea is used to express the assembly line balance and material supply scheme with chromosomes. Piecewise coding with a chromosome length of 2I is used.

The first I segment indicates the assignment of the job element and the station number, and the value on the gene string indicates the station to which the task is assigned. The last I segment indicates the allocation of the supply strategy, using binary coding, and the value on the gene string indicates the supply strategy used for the task. (See Fig. 6)



Figure 6. Genetic coding.

# VI. COMPUTATINAL EXPERIMENT

# A. Raw Data

In a rectangular workshop, there are three areas: assembly line, RDC and warehouse. Assume that the straight line distance of the vehicle from the warehouse to the assembly line is L. For convenience, the travel distances of different materials to the line are the same. There are three sizes of large, medium and small parts required for production. See Table II for details of parts and vehicle travel distance, Table III for production time.

TABLEII	PART PARAMETER	TABLE
I ADLL II.	I AKTI I AKAWETEK	IADLE

parameter	Small(25%)	Middle(50%)	Big(25%)
$a_i^{,z}$	[5,10]	[10,15]	[15,25]
$n_i$	1	5	10
$\eta^{\scriptscriptstyle P}_{\scriptscriptstyle i}$	[500,1000]	[200,500]	[50,200]
$a_i^{mc}$	1	2	4
L	500	1000	2000

TABLE III. PRODUCTION TIME

Work i	TAi	TBi	occupation
1	9.6	9.4	(1,4)
2	16	16	(2,1)
3	4.6	10	(0,3)
4	8.3	8.3	(1,3)
5	6.4	6.4	(0,5)
6	7.6	7.6	(3,3)
7	29.5	29.5	(8,16)
8	17.8	17.8	(4,7)

In this paper, MATLAB software is used to implement the above algorithm program, and data from www.assembly line balancing.de is used for testing. The parameters are set as follows, the number of work stations Num\_Work = 3, the population size popsize = 10, the maximum number of iterations GnMax = 500, the cross probability Pc = 0.8, and the mutation probability Pm = 0.05. The iterative process of the joint model piecewise genetic algorithm is shown in Fig. 7. We also solved the genetic algorithm iterative graph of the two-stage model for comparison shown in Fig. 8.



Figure 7. Two-stage model search process



In this paper we only consider the minimum production time and transportation time, that is, (the minimum objective function). The genetic algorithm is used to solve the problem. The assignment scheme and

TABLE IV. OPERATION RESULT

time of the two models are shown in Table IV.

Modeling approach	Two-stage model	Joint model
	Station1(125)	Station1(1 2 4 6)
allocation plan	Station2(347)	Station2(35)
	station3(78)	station3(78)
Supply strategy	All direct supply	4、5 Indirect supply, all others are directly supplied
total time	2942s	3276s
Space occupancy	Insufficient capacity of buffer area 1	All satisfy

#### VII. CONCLUSION

Aiming at the insufficient capacity of the buffer area of the assembly line of the production workshop, this paper believes that different packing methods of materials can effectively alleviate the lack of space and improve the production efficiency of the workshop. Therefore, a balanced design scheme of mixed-flow assembly line considering material supply strategy is proposed.

(1) Considering the limitation of the capacity of the buffer area, the effects of different supply strategies on the assembly line balance and their time conversion methods are analyzed to make the assembly line balance problem more practical.

(2) A joint optimization model is constructed that includes material handling time, material transportation time, and assembly line working time as the objective function. The equilibrium design of assembly line considering different supply strategies considering the buffer space is analyzed, and a genetic algorithm for solving the model is designed. Using the proposed algorithm, a practical and feasible balance scheme was produced, and the superiority of the joint modeling was proved through the comparison of the two-stage models.

# CONFLICT OF INTEREST

The authors declare no conflict of interest

#### AUTHOR CONTRIBUTIONS

Zhou yujia discovered the problems mentioned in the thesis and creatively proposed an understanding method, and completed the writing of the overall article; Shen Jin and Wu Bin mainly guided the general format and writing ideas; Chang Daofang provided experimental data.

#### ACKNOWLEDGMENT

This research is supported by Shanghai Pu Jiang Program (No. 17PJC051) and Natural Science Foundation of Shanghai (18ZR1413200)

#### REFERENCES

- J. Miltenburg and G. Sinnamon, "Scheduling mixed-model multilevel just-in-time production systems," *International Journal of Production Research*, vol. 27, no. 9, pp. 1487-1509, 1989.
- [2] L. Jinlin, G. Jie, and S. Linyan, "Equilibrium of mixed flow assembly line considering demand fluctuation and cost of capacity adjustment," *System Engineering Theory and Practice.*
- [3] L. Jinlin, C. Xiaohong, and G. Jie, "Balance of mixed-flow assembly lines with multi-functional workers to meet demand fluctuations," *Systems Engineering Theory & Practice.*
- [4] J. Sternatz, "The joint line balancing and material supply problem," *International Journal of Production Economics*, vol. 159, pp. 304-318, 2015.
- [5] D. Battini, M. Calzavara, A. Otto, *et al.*, "The integrated assembly line balancing and parts feeding problem with ergonomics considerations," *IFAC-PapersOnLine*, vol. 49, no. 12, pp. 191-196, 2016.
- [6] A. Nourmohammadi, H. Eskandari, M. Fathi, et al., "An integrated model for cost-oriented assembly line balancing and parts feeding with supermarkets," *Procedia Cirp*, vol. 72, pp. 381-385, 2018.

- [7] L. Wei, "Research on optimization of mixed-flow assembly line of forklift based on lean production," 2016.
- [8] Y. Jianyang, J. Xinli, and Z. Lu, "Collaborative optimization of balance and material distribution in hybrid assembly lines," *Mechanical and Electrical Engineering Technology*, vol. 45, no. 9, pp. 114-118, 2016.
- [9] W. Yongming, L. Lifei, D. Longzhou, *et al.*, "Collaborative optimization of assembly line balance and logistics distribution path," *Modular Machine Tool & Automatic Manufacturing Technology*, vol. 533, no. 7, pp. 186-189, 2018.

Copyright © 2021 by the authors. This is an open access article distributed under the Creative Commons Attribution License (<u>CC BY-NC-ND 4.0</u>), which permits use, distribution and reproduction in any medium, provided that the article is properly cited, the use is non-commercial and no modifications or adaptations are made.

**Yu-jia Zhou** was born in 1995 in Anhui province of China.She graduated in 2018 at Fuyang Normal University.Since 2018, she continued her postgraduate studies at Shanghai Maritime University. Research area is related to the Manufacturing logistics.

**Jin Shen** was graduated from Shanghai Jiaotong University in 2004 and went on to complete her master's and doctoral degrees at the same university. She is currently an associate professor at Shanghai Dianji University. Her main research directions are service-oriented manufacturing and product service operation system.

**Bin Wu** is now a professor of Shanghai Institute of electrical engineering. The main research directions are: 1. Energy and power engineering management; 2. Energy and power engineering project management.

**Daofang Chang**, graduated from China University of Mining and Technology with a bachelor's and master's degree, and then graduated with a Ph.D. from Shanghai Jiaotong University in 2012. Currently a professor at the Logistics Science and Engineering Research Institute of Shanghai Maritime University, his main research direction is logistics engineering and management.