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MIXED MODEL ASSEMBLY LINE BALANCING AND ASSEMBLY SEQUENCE SELECTION

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ABSTRACT

Mixed-model assembly line (MMAL) is a type of production line where a variety of product models similar to product characteristics are assembled. Line balancing and model sequencing problems are important for an efficient use of such lines. This paper presents integer programming formulation and a solution for a loading and assembly plan selection problem in a mixed-model assembly system. The problem objective is to assign assembly-tasks and products to stations and to select assembly sequences so as to balance the station workloads. For the solution of the problem, ILOG-CPLEX optimization studio is used.

Keywords: Production Systems, Line Balancing, Inreger programming

1. INTRODUCTION

Assembly is a manufacturing process of consecutively assembling components in order to produce a final product. Assembly lines are designed to produce high-quality and low-cost standardised homogeneous products. An assembly line is a flow-line production system in which a series of stations are arranged along a conveyor belt or a similar mechanical material handling system. An indivisible portion of the total work content in an assembly process is called a task, and the necessary time to perform a task is called the task time.

The tasks are allocated to stations according to a given precedence relationship among tasks. At each station, a task group, one or more tasks, is repeatedly performed by an operator in a limited duration time called the cycle time. After a cycle time, the unfinished products are moved from one station to its successive station until they reach the end of the line. At the last station, the product is completed and then it leaves the line [1]. As a result, assembly lines are used in most high-consumption industries in which the products are highly standardised, and are also increasingly used in companies that produce or assemble small quantities of products with a low level of standardisation.

Simple Assembly Line Balancing Problem (SALBP) is undoubtedly the most commonly studied line balancing problem. In this problem, it is assumed that there is one homogeneous product (no variants exist) to be assembled; all the details of the production process (the tasks and tools or machines) are known; the available time is the same for all stations (the cycle time of the line, which is known); the operation times are known and deterministic; no additional constraints are considered (besides precedence constraints); and the stations are serially distributed. The objective is to maximise the line efficiency (the sum of processing times divided by $m \cdot c$, m being the number of stations and c the cycle time), which means, depending on the version of the SALBP, to minimise the number of stations with a given cycle time (SALPB-1), to minimise the cycle time (*i.e.*, to maximise the production rate) with a given number of stations (SALBP-2) or to simultaneously minimise the cycle time and the number of stations (SALBP-E). When there is a known cycle time and number of stations (the pure version of SALBP), the objective is to find a feasible solution. Previous versions can be complemented by considering the secondary objective of smoothing the workstation times. Further details on the SALBP can be found in the surveys contained in the literature [2].

However, mixed-model assembly lines are also widely used in a range of industries which improve the flexibility to adapt to the changes in market demand. Mixed-model lines involve two important problems. The first is the mixed-model line balancing problem and the second is the model sequencing problem. The mixed-model line balancing problem is the problem of assigning tasks to an ordered sequence of stations in such a way that some performance measures are optimised, and the model sequencing problem is the problem of determining production sequence of models [3]. The research presents integer programming formulation of the Mixed Model Assembly Line problem with loading, routing and assembly plan selection problem is presented. A numerical example is presented in the last section.

2. SELECTION OF ASSEMBLY SEQUENCES AND BALANCING WORKLOADS IN MIXED MODEL ASSEMBLY LINE

The use of Mixed Model Assembly Lines in a changing environment requires methods for efficient design and re-design of the assembly system in which they are used. This assembly system design is focused on issues of assembly system or line configuration, balancing, and equipment selection. The use of programmable equipment and automation, along with human operators, necessitates design solutions that deal with optimal use of equipment and consider equipment costs, along with the objective of a balanced assembly line [4].

In a mixed model line it is necessary to decide on the sequence with which jobs will be released to the line. Because the jobs will not have identical time requirements, it is necessary to find sequences that do not overload the operators. In particular a job that requires somewhat more time to process at a work station should be followed by a shorter job so that the operator has time to catch up. For example, in automobile assembly, it would be usual to ensure that cars requiring air conditioning are spaced out in the sequence of job release because they require more work at some station [5].

The two main FAL short-term planning issues are loading and routing. Loading determines an assignment of assembly tasks (component feeders and appropriate assembly tools) to stations, whereas routing "xes assembly routes for a set of products to be simultaneously assembled. An assembly route is de"ned to be a sequence of stations that a product must successively visit to have all its components assembled with the base part [6].

In the following part, there is one computational study is solved using loading, routing, and assembly plan selection problem which is introduced by Tadeusz Sawik. A feasible solution of the combined loading, routing, and assembly plan selection problem must satisfy the following five basic types of constraints:

* each assembly task must be assigned to at least one station;
* for each product, only one assembly plan must be selected;
* for each product and assembly plan selected, all assembly tasks required must be completed;
* the total space required for the tasks assigned to each station must not exceed the station finite work space available;
* each product must be successively routed to the stations where the required tasks have been assigned subject to precedence relations defined by the assembly plan selected.

Minimize P_{max}, Q_{sum} (1)

Subject to

$$\sum_{i \in I_j} \sum_{l \geq i} y_{iljs} = u_s ; s \in S, j \in T_s \qquad (2)$$

$$\sum_{l\le i} y_{lijs} - \sum_{l\ge i} y_{ilrs} = 0; i \in I_r, (j,r) \in R_s, s \in S \qquad (3)$$

$$\sum_{k\in K}\sum_{s\in S_k}\sum_{j\in J_k}\sum_{l\ge i} p_{jk} y_{iljs} \le P_{\max}; i \in I \qquad (4)$$

$$\sum_{i\in I}\sum_{l\ge i}\sum_{s\in S}\sum_{j\in T_s} q_{il} y_{iljs} = Q_{sum} \qquad (5)$$

$$\sum_{i\in I_j} x_{ij} \ge 1; j \in J \qquad (6)$$

$$\sum_{j\in J} a_{ij} x_{ij} \le b_i; i \in I \qquad (7)$$

$$y_{iljs} \le x_{ij}; i \in I_j, l \ge i, l \in l_r, (j,r) \in R_s, s \in S \qquad (8)$$

$$y_{iljs} \le x_{lr}; i \in I_j, l \ge i, l \in l_r, (j,r) \in R_s, s \in S \qquad (9)$$

$$y_{iljs} \le u_s; i \in I_j, l \ge i, l \in l_r, (j,r) \in R_s, s \in S \qquad (10)$$

$$\sum_{s\in S_k} u_s = 1; k \in K \qquad (11)$$

$$y_{iljs} = 0; i \in I, l \langle i, j \in T_s, s \in S \qquad (12)$$

$$u_s \in \{0,1\}; \forall s \qquad (13)$$

$$x_{ij} \in \{0,1\}; \forall i, j \qquad (14)$$

$$y_{iljs} \in \{0,1\}; \forall i, l, j, s \qquad (15)$$

The following decision variables are introduced to model the combined loading, routing, and assembly plan selection problem (for notations used, see the Nomenclature):

u_s = 1, if assembly plan s E S is selected, otherwise u_s = 0;

x_{ij} = 1, if task j is assigned to station i $\in Ij$; otherwise x_{ij} = 0;

y_{iljs} = 1, if for assembly plan s, after completion of task j product is transferred from station i to station 1 to perform next task, otherwise y_{iljs} = 0;

The first objective function in (1) represents imbalance of the workload distribution. Minimization of the maximum workload $P_{\max}$ subject to (4) implicitly equalizes the station workloads. Constraint (2) ensures for each product and assembly sequence selected that all of its required tasks be allocated among the stations. Eqs. (3) give the flow conservation equations for each station, assembly sequence and a pair of successively performed tasks. Constraints (4) and (5) define the workload of the bottleneck station and the total transportation time, respectively. Constraint (6) ensures that each task is assigned to at least one station, and by this admits alternative assembly routes for products. Constraint (7) is the station capacity constraint. Constraints (8), (9) and (10) ensure that each product successively visits such stations where the required tasks may be assembled, subject to precedence relations defined by the assembly sequence selected. Constraint (11) ensures that only one assembly sequence is selected for each product. Finally, constraint (12) eliminates upstream flow of products in a unidirectional flow system [7].

3. COMPUTATIONAL EXAMPLE

In this section a simple numerical example is presented to illustrate application of the approach proposed by Tadeusz Sawik and some results of computational experiments are reported.

The system is made up of m=3 assembly stations i=*1, 2, 3* in series. There are five tasks to produce three different products. The material handling system is unidirectional with q=2 time units required for an AGV to move between any two neighbouring stations. k=3 different products are produced in this study. There are alternative assembly sequences are available for each product. The available sequences $s \in S_k$ of tasks $j \in J_k$ required to assemble each product k=*1, 2, 3* are illustrated below. For each assembly task *j* the working space a_{ij} required for the corresponding component feeders is independent on the station *i*, i.e., $a_{ij}=a_j, \forall i \in I_j, j \in J$ (a_{ij}=0 indicates that station *i* is incapable of performing task *j*). The available working space for each station is: $b_1=1, b_2=5, b_3=5$. *IJ* is the station making j tasks.

```
     k=1     S1:{1,3,5},
             S2:{1,5,3},
     k=2     S3:{1,2,4,5},
             S4:{1,4,2,5},
     K=3     S5:{2,3,5},
             S6:{2,5,3}];
```

[aij] = [[1 0 0],
[0 2 3],
[0 2 3]];
i = 3;
j = 5;
k = 3;
s = 6; IJ = [{1},{2,3},{2,3},{2,3},{2,3}];

p_{jk}, is the assembly time required for task $j \in J_k$ of product *k* and q_{il} the transportation time required to transfer a product from station i to station 1.

P_{jk}=[[4 4 0], [0 2 2], [2 0 2], [0 2 0], [4 4 4],]; q_{il} = [[0 2 4], [2 0 2], [4 2 0]],

The model is solved with ILOG CPLEX optimization studio. Resuts is shown in the following table.

Table 1.Computational Results

	Lambda 0	Lambda 0.5	Lambda 1
P_{max}	16	12	12
Q_{sum}	13	11	15
u	1,3,5	1,3,5	2,3,6

4. Conclusion

Mixed-model assembly lines are widely used in a range of industries which improve the flexibility to adapt to the changes in market demand. This paper includes integer programming formulation and a solution for a loading and assembly plan selection problem in a mixed-model assembly system. For this purpose a small example is solved using ILOG-CPLEX Optimization Studio. The results are shown at the last of paper.

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