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Operator assignment in a labor-intensive manufacturing cell considering inter-cell manpower transfer

Yiyo Kuo *, Chia-Chun Liu

Department of Industrial Engineering and Management, Ming Chi University of Technology, New Taipei City 24301, Taiwan

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ABSTRACT

This research deals with an operator assignment problem in which inter-cell manpower transfer is taken into consideration. A two phase methodology is proposed to minimize the total manpower required. In the first phase, integer programming is proposed to find the optimal configuration for allocation of tasks to workstations, and for each workstation one operator is assigned. The second phase uses mixed-integer programming to minimize the manpower required based on the results of the first phase. In addition, for the purpose of comparison, integer programming is also proposed for the situation where inter-cell manpower transfer is not allowed. A case study from a bicycle assembly company is introduced. The experimental results show that the proposed methodology can save manpower and improve manpower efficiency. Moreover, it also shows the promise of the method in solving practical applications.

1. Introduction

Operator assignment is one of the most important decisions that can achieve productivity gains in labor intensive manufacturing systems (Kuo & Yang, 2007). The purpose of this research is to optimize the operator assignment in a multi-cell and multi-period manufacturing system which is common in many industries. The motivation is a practical problem in a bicycle assembly company in Taiwan. The manufacturing system is assembly to order. Once the company receives an order, the company starts to order all the required components from all over the world, based on the specifications of the bicycle. Due to the trend of diversified demand, the volumes of orders are becoming smaller and smaller, while the total number of products in a year becomes more and more. Therefore, assembling a single product day after day is impossible, and there has to be frequent change over.

In the case company, the total assembly procedure is divided into two parts as shown in Fig. 1. The assembly tasks in the first part are easy to perform when the bicycle is hung under an overhead track and the assembly tasks in the second part are easy to perform when the bicycle is fixed upside down on a conveyor. After the assembly tasks in the first part are completed, the bicycles are hung under other overhead tracks and not moved to the conveyor for final assembly until all the components are prepared and the due date is imminent. Therefore there are two cells. The work-in-process hung under overhead tracks between these two cells is quite enough to keep the second cell busy or the second cell would be idle and must wait the output of the first cell. This research assumes that no bicycles assembled in the first cell will be moved to the second cell in the same day.

The product types in the company include general bike, road bike, mountain bike, downhill bike, BMX (Bicycle Motocross), ice bike, electric bike and so on. Even if the bicycles are the same type, the components are varied in design to meet the requirements of customers. For different bicycles the assembly procedure, tasks and tools are quite different. Therefore the processing time of tasks for different products are different. Table 1 shows the processing times of four products studied in this research in the first cell. There are a total of eight steps in the assembly procedure. The processing time of the first step of Product 1 is very small and the eighth step is not required for Product 4. When a given number of operators is available, no single configuration of operator assignment can efficiently assemble all different bicycles. Therefore, deciding the optimal configuration of operator assignment for all different bicycles could make the utilization of manpower more efficient.

To assemble different bicycles, a change over time is required for changing tools and arranging the components of the next product. However a change over time is also required when assembling the same bicycle with a different configuration of operator assignment, because some tasks will be executed by different operators. The corresponding operators have to change their tools and some arranged components have to be moved, but the changeover times for changing the configuration of operator assignment are quite short compared to those to change

* Corresponding author.
E-mail address: yiyo@mail.mcut.edu.tw (Y. Kuo).

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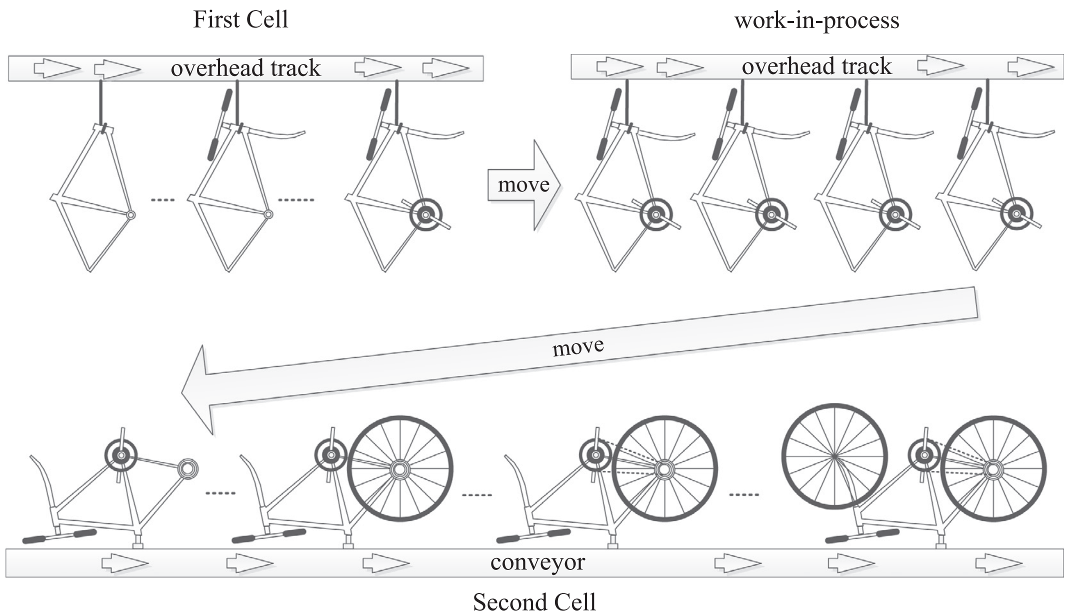

Fig. 1. The procedure of bicycle assembly.

Table 1
Processing times in Cell 1.

Step no.	Processing times (min)			
	Product 1	Product 2	Product 3	Product 4
1	0.03	0.62	0.05	0.18
2	0.52	0.68	0.50	0.73
3	0.22	0.50	0.45	1.00
4	0.33	0.42	0.48	0.73
5	0.25	0.57	0.43	0.95
6	0.25	0.42	0.13	0.18
7	033	0.17	0.17	0.30
8	0.28	0.42	0.82	–

product as all components have been located beside the overhead track or conveyor. Therefore, there are two types of changeover, product change and configuration change. In the case company, the work time is 8 h every shift, with overtime if necessary. There are two 10-min breaks and one 60-min break during each shift. Therefore, there are four production periods in a shift. All operators can be reassigned to other cells for different production periods. Thus inter-cell manpower transfer is allowed. However in the case company the decision to reassign operators is made without careful study, based on the intuition of the manager. The change over time caused by transferring operators is short compared with that caused by changing the bicycle. Therefore, when making the decision about operator assignment, there is an additional opportunity to utilize manpower more efficiently if inter-cell manpower transfer is taken into consideration.

This research deals with assigning operators for a multi-cell and multi-period manufacturing system in which inter-cell manpower transfer is allowed. The remainder of this paper is organized as follows. Section 2 reviews the pertinent literature. Section 3 presents the model formulation for the proposed problem. Section 4 presents the formulation of other models for comparison. Details of the empirical illustration are discussed in Section 5. Conclusions and future research opportunities are addressed in Section 6.

2. Literature review

Some literature related to operator assignment problems deal with a single cell. Nakade and Ohno (1999) deal with a U-shaped production line with multiple multi-function workers. They consider an optimization problem of finding an allocation of workers to the line that minimizes the overall cycle time and the minimum number of workers which satisfies the demand.

Ertay and Ruan (2005) proposed a U-shaped cellular manufacturing system. Considering 12 operator assignment alternatives, 2 demand levels and 2 transfer batch sizes, 48 scenarios are generated. The performances of all 48 scenarios are evaluated by simulation. Then data envelopment analysis (DEA) is adopted for determining the most efficient operator assignment. For the U-shaped cellular manufacturing system proposed by Ertay and Ruan (2005), Azadeh, Anvari, Ziaei, and Sadeghi (2010) consider 12 operator assignment alternatives and 3 shift patterns each day to generated 36 scenarios. The performances of all 36 scenarios are also evaluated by simulation. They propose integrated fuzzy DEA and fuzzy C-means to compare the scenarios. The results show that in all efficient scenarios the number of operators assigned is less than five. Moreover, Azadeh et al. (2010) made further comparison between the U-shaped system and 6 different types of system. The results show that the U-shaped system results are better than spiral, straight, L, W, zigzag, and Z systems. Based on the scenarios proposed by Azadeh et al. (2010), Azadeh, Kor, and Hatefi (2011) proposed a hybrid genetic algorithm (GA) and a technique for order performance by similarity to ideal solution (TOPSPS) to rank the scenarios. Azadeh, Asadzadeh, Mehrangohar, and Fathi (2014) proposed an integrated GA and analytic hierarchy process (AHP) to optimize operator assignment.

Besides U-shaped cellular manufacturing systems, Zaman, Paul, and Azeem (2012) address the operator assignment in a predefined workstation of an assembly line to produce a sustainable result. On the assembly line, each workstation consists of one or more different machines and only one operator is assigned. All operators are divided into several skill combinations. Operators with different skill combinations require different task times on different machines. They used GA to optimize productivity, cycle time and total idle time individually by determining the skill combination for each workstation.

In addition to single cell manufacturing systems, operator assignment problems in multi-cell systems can also be found in the literature. Süer (1996) proposed a two-phase hierarchical methodology to find the optimal manpower assignment and cell