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Optimal allocation of heterogeneous workers in a U-shaped production line

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Abstract

In this paper, we deal with a U-shaped production line with multiple heterogeneous multi-function workers. Skills of workers are assumed to be different. We consider an optimization problem for finding an allocation of workers to the line that minimizes the overall cycle time under the minimum number of workers satisfying the demand. All of processing, operation and walking times are deterministic. We propose an algorithm for computing an optimal allocation of workers to machines.

Keywords: The U-shaped production line; Multi-function workers; An optimal allocation

1. Introduction

In the *just-in-time* (JIT) production system, a single-unit production and conveyance system is applied to a production line without conveyors which manufactures different kinds of relatively small parts. To achieve this at a low production cost, a U-shaped layout is used with multi-function workers. When the same worker handles both machines at the entrance and the exit in the U-shaped layout, a new item enters the system only after one product is completed, and hence the work-in-process in the system is always constant. Furthermore, the number of different productive allocations of the workers to machines is greater than in the linear layout. Therefore, when the demand changes the workers to machines can be appropriately reallocated so that the cycle times of workers are balanced.

There are two types of figures in a U-shaped line. One is that there is no automated processing machine, and after each worker operates an item at a machine he takes it to the next machine and so on, and he hands it over to the adjacent worker. Miltenburg and Wijngaard (1994) have discussed the line balancing problem of the U-shaped line with constant operation times, no waiting times and no walking times. They have considered the optimal machine allocation problem to workers, which they called stations, under the precedence constraints. Zavadlev, McClain, and Thomas (1996) have considered a U-shaped line with no walking time.

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The fixed assignment where each worker has a fixed set of machines, and the shared assignment where some machines are shared among multiple workers, have been analyzed. They have also discussed the free assignment where after each worker finishes operating he/she moves backward or forward and searches an idle machine. They have shown the free assignment is effective than the fixed and shared assignment by simulation or Markov models. Sparling and Miltenburg (1998) have considered the mixed product U-shaped line. They have proposed an approximate algorithm to determine the minimal number of workers, the sequence of machines and the allocation of workers to the machines under precedence constraints of machines and the predetermined cycle time. Miltenburg (2001) has surveyed researches for such U-shaped lines.

In the second type of U-shaped lines operation of each machine consists of both automated processing and operations by workers. At each machine a multi-function worker works on multiple machines, and visits each of them once in one cycle, which is a time-interval between his consecutive arrivals at his first machine. When he arrives at one of these machines, he waits for the end of processing of the preceding item if it is not completed, and then operates the items and walks to the next machine after sending the processed item to this machine. This type of lines can be seen in making a sewing machine for example where processing of machine consists of drilling, attaching parts and so on. Since one worker handles products at several automated machines, his total walking time in one cycle is not negligible compared with processing and operation times. In this case, it is possible for the worker to wait for the end of processing at a machine for an allocation, because the time interval from departure to next arrival of the worker at the machine may exceed the processing time at the machine. Ohno and Nakade (1997) have obtained the cycle time in the U-shaped line and discussed the two worker allocation problem for a special case, and Nakade and Ohno (1999) have shown that the algorithm for finding the optimal worker allocation under the given demand. They have also discussed the line with stochastic times and shown the upper and lower bounds for expected overall cycle times.

In previous researches it is assumed that workers have the same skill to operate items at any machine. Recently, many temp staffs are employed as workers and they are committed into production lines because of cost reduction under global competition. For example, many foreigners and part-time workers by a few-month or one-year contract are employed in Japanese part-making and assembly production lines. Therefore, it becomes difficult to maintain the workers well-skilled in the long time, so that the workers' skills remain mutually different. In this case, well-skilled workers can operate items with short times at any machine, but new workers can operate items at only a few machines. Although Nakade and Ohno (1999) show the algorithm for optimal allocation of homogeneous workers, further consideration and development for finding optimal allocation of heterogeneous workers are needed because the formulation of the problem must be changed and the number of possible allocations of workers extremely increases, which leads to the huge increase of the amount of necessary memories and running times for computing.

In this paper, we consider an optimization problem for finding an allocation of such heterogeneous workers to the line that minimizes the overall cycle time under the minimum number of workers in the second type of U-shaped production line with automated processing. All of processing, operation and walking times are deterministic though they are different among workers. We propose an algorithm for computing an optimal allocation of workers to machines.

The organization of this paper is as follows. In Section 2, we describe the model. Section 3 discusses the types of optimal allocation problems, and in Section 4, we develop the algorithm for finding optimal allocation of workers. In Section 5, we give numerical results and we conclude this paper in Section 6.

2. Model

We consider a U-shaped production line with heterogeneous multi-function workers and machines shown in Fig. 1. The facility has enough raw material in front of machine 1. The material is processed at machines $1, 2, \ldots, K$, sequentially, and departs from the system as finished products. There are J multi-function workers who have different operation speeds. A part of workers handle several machines. Let M_j denote a set of machines which worker $j \in W = \{1, \ldots, J\}$ deals with. We set $M_j = \{k_{j1}, k_{j2}, \ldots, k_{jm_j}\}$, where $M = \{1, \ldots, K\} = \cup_{j\in W} M_j$ and $M_i \cap M_j = \phi$ for $i \neq j$. The set M_j is empty when worker j ($j = 1, 2, \ldots, J$) is not allocated, in which m_j is 0. This allocation is denoted by $(M_1, \ldots, M_J)$. It is assumed that when $m_j \geqslant 2$, M_j is restricted to one of the following two types: