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Robotic cell scheduling with operational flexibility

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Abstract

In this paper, we study the problem of two-machine, identical parts robotic cell scheduling with operational flexibility. We assume that every part to be processed has a number of operations to be completed in these two machines and both machines are capable of performing all of the operations. The decision to be made includes finding the optimal robot move cycle and the corresponding optimal allocation of operations to these two machines that jointly minimize the cycle time. We prove that with this definition of the problem 1-unit robot move cycles are no longer necessarily optimal and that according to the given parameters either one of the 1-unit robot move cycles or a 2-unit robot move cycle is optimal. The regions of optimality are presented.

Keywords: Robotic cell; Cyclic scheduling; Automated manufacturing

1. Introduction

In order to be successful in today's highly competitive world, increasing productivity is an essential factor for manufacturing systems. Recent technological improvements opened new perspectives for industries. As a result, many industries are making use of automation, and hence the use of robots in industry is increasing rapidly. Robots are installed in order to reduce labor cost, to increase output, to provide more flexible production systems and to replace people working in dangerous or hazardous conditions [3]. An important application of robots in manufacturing is their use as material handling devices in robotic cells, where a robotic cell contains two or more robot-served machines [10]. There are no buffers at or between the machines. For the complexity of unlimited buffer space problem, we refer to Hurink and Knust [9]. Logendran and Sriskandarajah [11] study three different robotic cell layouts: robot-centered cells (where the robot movement is rotational), in-line robotic cells (where the robot moves linearly) and mobile-robot cells (generalization of in-line robotic cells and robot-centered cells). Sethi et al. [12] proved that for a 2-machine robotic cell producing a single part type, the optimal solution is a 1-unit cycle, where an n-unit cycle can be defined as a robot move cycle which produces exactly n units and ends up with the same state of the cell as the starting state. Hall et al. [8] proved that for three machine cells, producing single part-types, the repetition of 1-unit cycles dominates more complicated policies that produce two units. Crama and Klundert [6] established the validity of the conjecture of Sethi et al. [12] that "1-unit cycles yield optimal production rates for 3-machine robotic flowshops". Brauner and Finke [2] proved that 1-unit cycles do not necessarily yield optimal solutions for cells of size four or large. Reviews of the literature related to cyclic scheduling problems in robotic cells without buffers can be found in Crama et al. [4] and Sriskandarajah et al. [13].

In the current literature, the allocation of the operations to each machine is assumed to be constant and for given processing times the optimum robot move cycle minimizing the cycle time is to be determined. In some manufacturing

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operations such as chemical electroplating this assumption is meaningful and these operations mostly require no-wait constraints (see for example [1]). However, in flexible manufacturing systems (FMS) the processing stations are predominantly CNC machines and they possess *operation flexibility* by definition. Operation flexibility can be defined as the ability to interchange the ordering of several operations for each part type [3]. Therefore, assuming that processing times are fixed on each CNC machine may not accurately represent the capabilities of the CNC machines and limits the number of alternatives unnecessarily for these systems. In this study we assume that each part has a number of different operations to be completed. Henceforth, the problem to be considered is to allocate the operations to the machines and is to find the robot move cycle that corresponds to this allocation of operations in order to jointly minimize the cycle time or in other words, maximize the long run average throughput rate.

For this problem definition, we prove that the optimal solution is not necessarily a 1-unit cycle as in the case of Sethi et al. [12] and show that the optimal solution could be a 2-unit cycle for some parameter input. We present regions of optimality for the potentially optimal robot move cycles.

The remainder of the paper is organized as follows. In the next section we present the problem definition and 1-unit robot move cycles. The operation allocation problem is described in Section 3. In Section 4, sensitivity analysis on parameters is made and in Section 5, we comment on the results and suggest new research directions.

2. Preliminaries and problem definition

This section reviews some standard terminology from the literature and introduces several definitions particular to this paper. Also in this section we give a formal definition of our problem and introduce our systematic approach in cycle time calculations.

We consider an in-line robotic cell of two identical machines which repeatedly produces one type of product. There is no buffer between the machines. The layout of the cell can be seen in Fig. 1. Each of the identical parts has a number of operations to be performed. The processing times are assumed to be identical for every operation in both of the machines. Consistent with the existing literature (see [12]), the loading and unloading times and the travel time of the robot from one station to a consecutive station are all assumed to be constant. Furthermore, the robot travel times satisfy the triangular equality (see [6]).

In this study, we consider the robotic cell to be composed of CNC machines and a material handling robot. The CNC machines possess operational flexibility and process flexibility by definition. Browne et al. [3] defines process flexibility as the ability to handle a mixture of operations. That is, if a part requires different operations such as drilling, milling, etc., process flexibility states that, one CNC can handle all of these operations. This is achieved by the tool magazines of these CNC machines which are capable of changing the tools easily and with very small setup times. On the other hand, operational flexibility is defined as the ability to interchange the ordering of several operations for each part type. That is, the processing sequence of operations required for a part type can be changed. In this study we assume that the operations constituting each part may be processed in any order. These two types of flexibilities make it possible to allocate every operation to any one of the two machines. As the allocation of the operations changes, the processing times on the machines also change accordingly. As a result, in our study the processing times are not fixed but rather are decision variables. We will try to find the processing times on both of the machines by allocating the operations to the machines and finding the robot move cycle which will jointly minimize the cycle time.

The following definitions on robot activities and n-unit robot move cycles are borrowed from Crama and Van de Klundert [5].

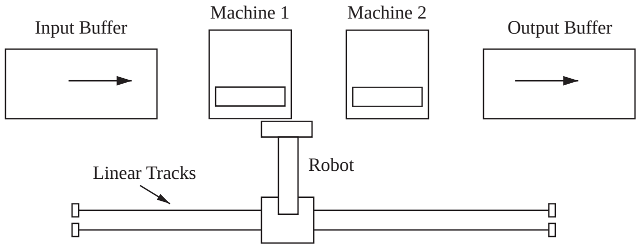

Fig. 1. Inline robotic cell layout.