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Scheduling in a three-machine robotic flexible manufacturing cell

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Abstract

In this study, we consider a flexible manufacturing cell (FMC) processing identical parts on which the loading and unloading of machines are made by a robot. The machines used in FMCs are predominantly CNC machines and these machines are flexible enough for performing several operations provided that the required tools are stored in their tool magazines. Traditional research in this area considers a flowshop type system. The current study relaxes this flowshop assumption which unnecessarily limits the number of alternatives. In traditional robotic cell scheduling literature, the processing time of each part on each machine is a known parameter. However, in this study the processing times of the parts on the machines are decision variables. Therefore, we investigated the productivity gain attained by the additional flexibility introduced by the FMCs. We propose new lower bounds for the 1-unit and 2-unit robot move cycles (for which we present a completely new procedure to derive the activity sequences of 2-unit cycles in a three-machine robotic cell) under the new problem domain for the flowshop type robot move cycles. We also propose a new robot move cycle which is a direct consequence of process and operational flexibility of CNC machines. We prove that this proposed cycle dominates all 2-unit robot move cycles and present the regions where the proposed cycle dominates all 1-unit cycles. We also present a worst case performance bound of using this proposed cycle.

Keywords: Robotic cell; Cyclic scheduling; Automated manufacturing

1. Introduction

Industrial robots are used extensively in manufacturing companies performing tasks ranging from assembly to testing and inspection. Material handling is one of the important applications of robots. A manufacturing cell in which loading and unloading operations are made by robots is called a robotic cell. These kinds of robots are used extensively in chemical, electronic and metal cutting industries. In this study, we restrict ourselves to robotic cells used in machining applications. The machines used in such systems are predominantly CNC machines and they are capable of performing several different operations by fast and inexpensive tool changes. Consequently, we assume that, each part to be processed has a fixed number (p) of operations with identical operation times on the three machines (t_l for operation l) which can be performed in any order on the three machines. Furthermore, we assume that each operation can be assigned to any one of the machines.

Three different cell layouts are considered in the literature for robotic cells: 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 cell and robot-centered cell) [1]. In this study we deal with the in-line robotic cell layout with three

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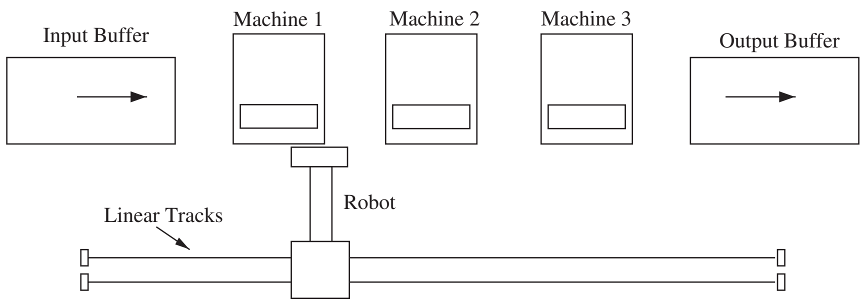

Fig. 1. Inline robotic cell layout.

machines as shown in Fig. 1. In these cells the robot moves on the linear tracks to transport the parts between the machines. After loading a part on one of the machines, the robot either waits in front of the machine to finish the processing, moves to unload another machine or moves to input buffer to take another part and load the first machine. At any time instant, a part is either on one of the machines, on the robot or at the input or output buffer. Crama et al. [2] state the following assumptions which can be referred to as *basic feasibility assumptions*:

(i) Robot never loads an already loaded machine.
(ii) Robot never unloads an already empty machine.

A state of the system can be specified by the position of the robot and whether the machines are loaded or empty. Consistent with the literature, we will deal with cyclic schedules in this study. A cyclic schedule is one in which the robot performs the same set of activities continuously. A cycle starts with an initial state of the system, the robot performs a set of activities and when the system returns back to the initial state, the cycle is completed. A cycle in which n parts are produced is called an n-unit cycle.

Various problems concerning the robotic cells arise in the literature. Crama et al. [2] and Dawande et al. [3] provide extensive surveys in this research area. Sethi et al. [4] developed the necessary framework and proved that for 2-machine identical parts case, the optimal solution is a 1-unit cycle and conjectured that 1-*unit cycles are optimal for m-machine robotic cells*. They also proved that the number of 1-unit cycles in the m-machine case is exactly $(m!)$. The validity of the conjecture of Sethi et al. [4] for 3-machine robotic flow-shops is established by Crama and Van de Klundert [5]. Brauner and Finke [6] simplified this proof. In a later study, Brauner and Finke [7] proved that 1-unit cycles do not necessarily yield optimal solutions for cells of size four or large. Hall et al. [8] showed that for multiple part types, even in 2-machines case there are instances for which 1-unit cycles are dominated. Aneja and Kamoun [9] proposed an $O(n \log n)$ time algorithm for the same problem which determines the optimal robot move cycle and the part input sequence simultaneously. Geismar et al. [10] developed a 1.5 approximation for the multi-unit cyclic solution. Akturk et al. [11] considered a robotic cell with two identical CNC machines which possess operational and process flexibility. For this problem, they proved that 1-unit cycles are not necessarily optimal and that a 2-unit cycle can also be optimal and presented the regions of optimality.

Current study deviates from the existing literature in that we assume the robotic cell to be a flexible manufacturing cell (FMC). An FMC is a production cell consisting of CNC machines, connected through an automated material handling system and controlled by a centralized computer. "Flexibility" is the key term which distinguishes FMCs from traditional ones. There are several types of flexibilities such as machine, material handling, operation, process and routing flexibilities. In this study we consider operation flexibility (the ability to change the ordering of several operations) and process flexibility (the ability of machines to perform multiple operations). Such flexibilities are achieved by considering alternative tool types for operations and loading multiple tools to the tool magazines of the machines.

Furthermore, in this study we will investigate the additional flexibility introduced by the CNC machines. A new robot move cycle which is a direct consequence of operational and process flexibilities will be proposed. We will compare the cycle times (throughput values) of the proposed cycle and the robot move cycles considered in the literature thus far and exhibit the regions of optimality.