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A framework for stochastic scheduling of two-machine robotic rework cells with in-process inspection system

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ABSTRACT

This study is focused on the domain of a two-machine robotic cell scheduling problem for three various kinds of pickup scenarios: free, interval, and no-wait pickup scenarios. Particularly, we propose the first analytical method for minimizing the partial cycle time of such a cell with a PC-based automatic inspection system to make the problem more realistic. It is assumed that parts must be inspected in one of the production machines, and this may result in a rework process. The stochastic nature of the rework process prevents us from applying existing deterministic solution methods for the scheduling problem. This study aims to develop a framework for an in-line inspection of identical parts using multiple contact/non-contact sensors. Initially, we convert a multiple-sensor inspection system into a single-sensor inspection system. Then, the expected sequence times of two different cycles are derived based on a geometric distribution, and finally the maximum expected throughput is pursued for each individual case with free pickup scenario. Results are also extended for the interval and no-wait pick up scenarios as two well-solved classes of the scheduling problem. The waiting time of the part at each machine after finishing its operation is bounded within a fixed time interval in cells with interval pickup scenario, whereas the part is processed from the input conveyor to the output conveyor without any interruption on machines in cells with no-wait pickup scenario. We show a simple approach for solving these two scenarios of the problem which are common in practice.

1. Introduction

Robotic cells are one of the complicated application areas of flow-shops that have received a considerable amount of attention in different areas such as robot path planning (Macharet, Monteiro, Mateus, & Campos, 2016; Ting, Lei, & Jar, 2002), robot selection (Bairagi, Dey, Sarkar, & Sanyal, 2015; Parkan & Wu, 1999), task allocation in robotic systems (Kim, Kim, & Lee, 2012) and robot move sequencing (Brauner, 2008; Kats & Levner, 2011). They are basically classified into two categories: the robotic cells without rework assumption and robotic rework cells. The term "rework" here means that a processed part may need reprocessing. Therefore, it is cycled between test and processing stations until deemed acceptable. It is straightforward to find a deterministic model for the robotic cells without rework assumption. Following that, there are many studies in the literature dealing with the scheduling of the robot activities, as widely addressed in Dawande, Geismar, Sethi, and Sriskandarajah (2005) for two-machine cells. Nonetheless, inspection and rework stages in a robotic cell is one of the important issues in the field of robotic cell scheduling which reflects most real-life cases. This paper addresses the stochastic issues that arise when considering inspection and rework stages, laying some important analytical foundations for this under-studied problem.

A robotic cell with an additional inspection process in one of the rework stages is called a robotic rework cell. A two-machine robotic rework cell which is the smallest possible robotic rework cell is commonly captured by the following framework: the cell is made up of two production machines M_1 and M_2, multiple contact/non-contact sensors installed into M_1 or M_2, a gantry robot that serves the entire production line, an input conveyor (I or the axillary machine M_0) and an output conveyor (O or the axillary

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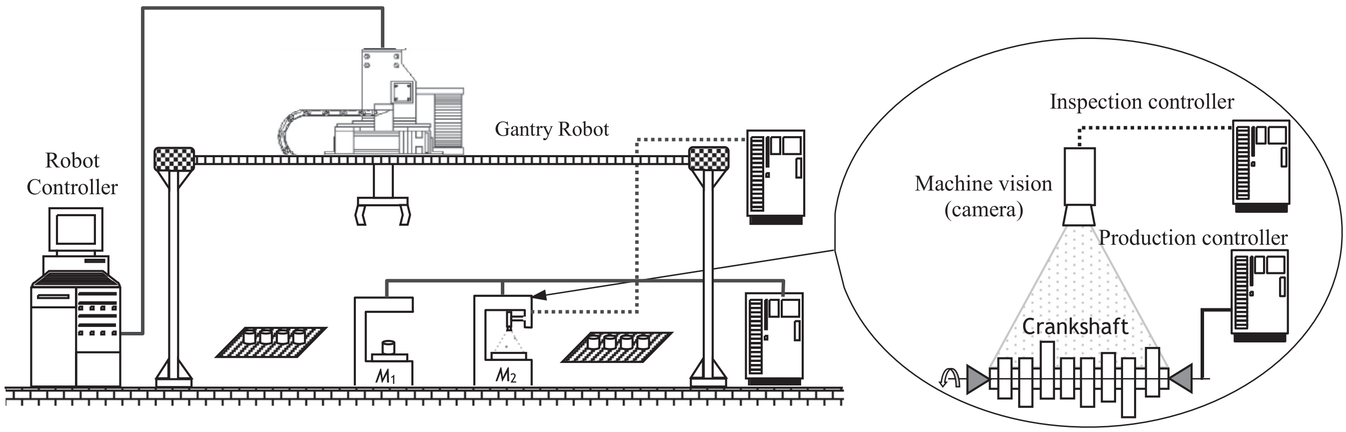

Fig. 1. A two-machine robotic rework cell with end of line inspection.

machine M_3) with unlimited storage capacity. This framework makes it clear that typical robotic cells are a special case of robotic rework cells where there is no inspection sensor on production machines, and all produced parts are failure-free.

Two-machine robotic rework cells are classified into two groups: two-machine robotic rework cells with start of line inspection (RRCSI) and two-machine robotic rework cells with end of line inspection (RRCEI). They are also called "Start of Line" testing and "End of Line" testing, respectively. An example of two-machine robotic rework cells with end of line inspection is shown in Fig. 1 for the crankshaft production lines (Ayub, Mohamed, & Esa, 2014). A particular crankshaft being processed goes through I, the lathe machine M_1, the lathe machine M_2 and O under this part processing route. After loading the crankshaft to any one of the lathe machines, the robot either waits for the crankshaft to finish its operation or immediately moves to another occupied lathe machine or I for unloading a new crankshaft. The difference between two machines is that the crankshaft is failure-free when it is processing on M_1, whereas the crankshaft may fail and need rework when it is processing on M_2.

Another example of robotic rework cells with inspection is extracted from cluster tools which are employed in processes such as deposition and inspection. The reason why we give this example is that cluster tools actually act as closed mini-environment robotic cells (Dawande et al., 2005). For fabrication of wafer in cluster tools, atomic layer deposition (ALD) is a process that controls the wafer thickness by repeating the deposition processes with mono-atomic layer precision as needed. The quality of the wafer is often inspected by Spectroscopic Ellipsometry (SE) inspection method in order to check whether a conformal layer is fabricated. Therefore, the thickness of the wafer is inspected by SE method during madding the depositions of each layer on wafer (Langereis et al., 2009).

We should mention that a wide variety of real-life studies of production environments have been conducted on noncyclic production aiming at minimization of the maximum completion time (also referred to as makespan) (Chu, Chu, & Desprez, 2010; Elmi & Topaloglu, 2013). However, this study is limited to cyclic scheduling of the robotic rework cell due to its popularity in mass production environments in which the robot is applied for material handling. A cyclic schedule is based on a repeating pattern of part processing (Sinan Kayaligil & Ozlu, 2002). Robotic cells under consideration in this study can do rework processes, and consequently the stochastic nature of the rework process prevents us from applying existing deterministic solution methods for the cyclic scheduling problem. Therefore, the study of robotic cells without rework assumption, which has a deterministic processing route, will be briefly reviewed in this paper. We refer readers to the rigorous analysis of robotic cells with deterministic data elaborated in the book by Dawande, Geismar, Sethi, and Sriskandarajah (2007).

It is interesting to address the following recent studies for three kinds of pickup scenarios: free, interval, and no-wait pickup scenarios. For the free pickup scenario with deterministic data, all corresponding studies assumed that the waiting time of the part on the machine is unbounded. The approach in Geismar, Manoj, Sethi, and Sriskandarajah (2012) jointly analysed design and scheduling problems when the type of the robot is dual-arm. An analytical approach for optimization of the cycle time of two-machine reentrant robotic cells was presented in Foumani and Jenab (2012). The distinguishing feature of the robot in Foumani and Jenab (2012) is that it has a one-unit portable buffer on its end-effector that can increase productivity. Adopting a genetic algorithm, the impact of setup time consideration on the optimal cycle was analysed in Zarandi, Mosadegh, and Fattahi (2013). Following that, in Atabak Elmi and Topaloglu (2016), an ant colony algorithm was adopted for the multi-degree scheduling problem with multiple robots. The metaheuristic algorithm concurrently find the degree of the schedule, a robot task assignment matrix, and cycles of robots that minimize the cycle time. Finally, robotic cells with parallel machines was studied in Zabihzadeh and Rezaeian (2016) where an ant colony algorithm and a genetic algorithm were adopted. The computational results of this study have shown that the genetic algorithm has a higher performance in comparison with the ant colony algorithm.

Additionally, a large number of works can be found in the literature for problems with interval and no-wait pickup scenarios (Levner, Kats, David Alcaide López de Pablo, & Cheng, 2010). The reason behind this interest in interval and no-wait pickup scenarios is that they are more suitable for real-world problems than free pickup scenario which is a simplified version of them. Let us initially give a brief literature review on the recent problems with the interval pickup scenario. The interval pickup scenario is commonly seen in chemical industry where the waiting time of the part on the machine is bounded within a pre-defined time interval. More precisely, an applications of such cells can be found in the hoist scheduling problem on an electroplating line. For this problem, a set of electroplating baths with various chemicals are serially employed to layer a part. It should be noted that the automatic hoist, which can be a robot, transfer parts between