FMS Scheduling Integration for Mass Customization

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Abstract. In today's manufacturing and supply chain environments, many companies face challenge in responding to customers' requirements quickly and providing customized products quickly at low cost. Mass customization can help companies in providing customized products and services quickly and at a low price. Integrated decision-making has been found effective in many situations. This paper reviews the scheduling research of flexible manufacturing systems (FMSs). The FMS scheduling problem is part of the FMS production and operation management problem. Because the production management of FMSs is very difficult, the FMS scheduling problem is very complicated. Many researchers have investigated the FMS scheduling problem. The paper summarizes the FMS scheduling research with recent development. In addition, a framework of FMS scheduling integration for mass customization is developed based on the literature survey. A control flow of FMS part processing is designed as part of the framework. Further development of the FMS scheduling integration is suggested.

Keywords: Mass customization · Flexible manufacturing system · FMS scheduling · Scheduling integration

1 Introduction

Contemporary manufacturing and supply chain environments are dynamic and changing. It often occurs that customers' requirements need to be satisfied quickly and accurately at a low price [1]. Mass customization (MC) is aimed to provide customized products and services with low cost and high quality in changing environments [2]. Integrated decision-making has been found effective to adequately manage various conflicting objectives and to make coordination control [3–5].

Flexible manufacturing systems (FMSs) can be used to automate mass customization [2]. The production management of FMSs is more difficult than that of mass production lines and job shops [6]. Orders sent to a capacity constrained FMS might not be processed on time and excess-capacity parts have to be sent to a job shop [7]. He, Stecke, and Smith [8] investigated simultaneous robot and machine scheduling with part input sequencing in FMSs for mass customization. Interactions between FMS robot scheduling and machine scheduling with part input sequencing are found. He and Stecke [9] investigated the

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problem of simultaneous FMS part input sequencing and robot scheduling and suggested the integration of simultaneous FMS part input sequencing and robot scheduling with operation scheduling.

This paper reviews the FMS scheduling research in the area of FMS part input sequencing, robot scheduling, and machine scheduling. The FMS scheduling research with recent development is presented. Based on the literature survey, a framework of FMS scheduling integration for mass customization is developed. A control flow of FMS part processing is designed as part of the framework.

2 FMS Scheduling

Many researchers have investigated the FMS scheduling problem. The FMS scheduling research is summarized in the following as FMS part input sequencing, sequencing and scheduling in FMSs with robot material handling, and machine scheduling with FMS material handling.

2.1 FMS Part Input Sequencing

FMSs can be classified as flexible flow systems (FFSs) and general flexible machining systems (GFMSs) [10]. FFSs include flexible assembly systems and flexible transfer lines. General flexible machining systems include both dedicated and nondedicated flexible machining systems. A flexible machining cell (FMC) is a single machine and its associated equipment [11].

FMS part input sequencing has been studied with the FMS production planning problems in earlier studies. For example, Stecke and Kim [12] developed a modified Johnson's algorithm for FFSs. Stecke [13] developed several approaches to solve the FMS part input sequencing problem. Research on FMS part input sequencing is summarized in Table 1.

2.2 Sequencing and Scheduling in FMS with Robot Material Handling

Researchers have studied sequencing and scheduling in FMS with robot material handling. For example, Sethi *et al.* [27] studied a real FMS with a robot, two or three machine tools, and a single part type to maximize throughput. Sriskandarajah *et al.* [28] scheduled a bufferless dual-gripper robot handling multiple part types to maximize throughput.

Dawande *et al.* [30] surveyed robot move sequencing and part scheduling in FMSs with robot material handling. Research on sequencing and scheduling in FMS with robot material handling is summarized in Table 2.

2.3 Machine Scheduling with FMS Material Handling

Researchers have studied machine scheduling with FMS material handling. In earlier studies, Blazewicz et al. [37] proposed a pseudo-polynomial dynamic programming approach to schedule machine and vehicle. Sabuncuoglu and Hommertzheim [38] proposed a dynamic dispatching algorithm to schedule machines and AGVs. Research on machine scheduling with FMS material handling is summarized in Table 3.

Table 1. Summary of research on FMS part input sequencing.

No	Author	Subject	Objective	Year
[12]	Stecke, Kim	Part type selection, part input	Over & under load	1991
[13]	Stecke	Part input sequencing	Over & under load	1992
[14]	O'Keefe, Rao	Part input	Makespan, throughput	1992
[15]	Kim, Yano	Part type selection	Total tardiness	1994
[16]	Smith, Stecke	Part input sequencing	Balancing workload	1996
[17]	Leu	Order-input sequencing	Set up time	1999
[18]	Sawik	Sequential loading	Production time	2000
[19]	Sawik	Blocking scheduling	Completion time	2001
[20]	Kim, Lee, Yoon	Part input sequencing	Makespan	2001
[21]	Sawik	Simultaneous balancing and scheduling	Completion time	2002
[22]	Lacomme, Moukrim, Tchernev	Job-input sequencing	Makespan	2005
[23]	He, Smith	Part input sequencing	Production	2007
[24]	Gusikhin, Caprihan, Stecke	Input sequencing	In-sequence parts, buffer size	2008
[25]	Sawik	Batching scheduling, cyclic scheduling	Completion time	2012
[26]	He *et al.*	Part input sequencing	Production	2015

Table 2. Summary of research on sequencing and scheduling in FMS with robot material handling.

No	Author	Subject	Objective	Year
[27]	Sethi *et al.*	Sequencing parts and robot moves	Long run average throughput	1992
[28]	Sriskandarajah *et al.*	Robot move sequencing, part sequencing	Throughput rate	2004
[29]	Geismar *et al.*	Cyclic scheduling	Throughput	2005
[31]	Dawande, Pinedo, Sriskandarajah	Cyclic scheduling	Throughput	2009
[32]	Yildiz, Akturk, Karasan	Cyclic scheduling	Cycle time	2011
[33]	Zahrouni, Kamoun	Sequencing parts and robot activities	Cycle time	2012

(*continued*)

Table 2. (*continued*)

No	Author	Subject	Objective	Year
[34]	Che, Kats, Levner	Robotic flow shop scheduling	Cycle time, stability radius	2017
[35]	Gultekin, Coban, Akhlaghi	Cyclic scheduling	Throughput rate	2018
[36]	Foumani, Razeghi, Smith-Miles	Cyclic scheduling	Partial cycle time	2020
[9]	He, Stecke	Simultaneous part input sequencing and robot scheduling	Production	2021

Table 3. Summary of research on machine scheduling with FMS material handling.

No	Author	Subject	Objective	Year
[37]	Blazewicz *et al.*	Production scheduling, vehicle scheduling	Completion time	1991
[38]	Sabuncuoglu, Hommertzheim	Scheduling machines and AGVs	Mean flowtime, mean tardiness	1992
[39]	Ulusoy, Bilge	Simultaneous scheduling, of machines and AGVs	Makespan	1993
[40]	Bilge, Ulusoy	Simultaneous scheduling, of machines and AGVs	Makespan	1995
[41]	Abdelmaguid *et al.*	Simultaneous scheduling, of machines and AGVs	Makespan	2004
[42]	Deroussi, Gourgand, Tchernev	Simultaneous scheduling, of machines and AGVs	Makespan	2008
[43]	Babu *et al*	Simultaneous scheduling, of machines and AGVs	Makespan	2010
[44]	Lacomme, Larabi, Tchernev	Simultaneous scheduling, of machines and AGVs	Makespan	2013
[45]	Zheng, Xiao, Seo	Simultaneous scheduling, of machines and AGVs	Makespan	2014
[46]	Baruwa, Piera	Simultaneous scheduling, of machines and AGVs	Makespan	2016
[8]	He, Stecke, Smith	Part input sequencing, machine and robot scheduling	Total parts produced, robot utilization, mean flowtime	2016
[47]	Nouri, Driss, Ghedira	Simultaneous scheduling of machines and transport robot	Makespan	2016

3 Framework of FMS Scheduling Integration

A framework of FMS scheduling integration for mass customization is developed based on the literature survey. The framework is illustrated in Fig. 1. The FMS is composed of CNC machines and a robot for material handling. The framework includes an information processing center that is composed of computers, servers, and tools to process information. The center can process data and information exchanged through internet, intranet, and extranet. It can also process data and information obtained from RFID. RFID technology is the significant advance in managing dynamic systems [48].

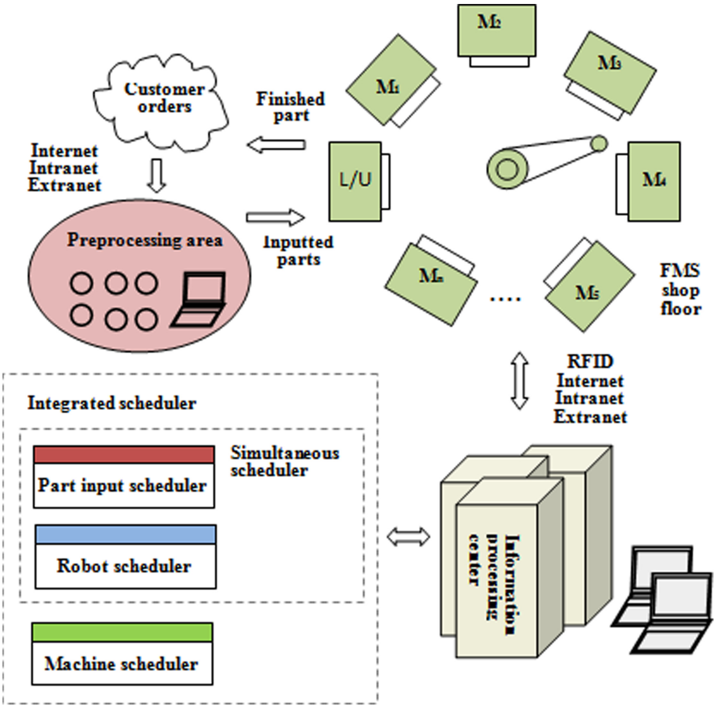

Fig. 1. Illustration of FMS scheduling integration.

The framework also includes a scheduler for FMS scheduling integration. The scheduler is composed of an FMS part input scheduler, an FMS robot scheduler, and an FMS machine scheduler. Scheduling algorithms found in the literature can be used as the schedulers. The algorithm for FMS part input sequencing developed in [23, 26] can be used as the FMS part input scheduler. The algorithm for FMS robot scheduling developed in [49] can be used as the FMS robot scheduler.

The combination of the FMS part input scheduler and the FMS robot scheduler can result in the simultaneous scheduler. The algorithm for simultaneous FMS part input sequencing and robot scheduling has been developed in [9]. The integrated scheduler for the FMS scheduling integration can be developed by integrating these individual schedulers. It can also be developed by combining the simultaneous scheduler with the FMS machine scheduler.

A control flow of FMS part processing is designed. The control flow is aimed to illustrate part flow and control decision making in the FMS. The control flow is explained in the following. Inputted parts are waiting for loading and unloading (L/U). If the L/U is available, a part is loaded to the FMS. Parts are waiting for the robot for moving. If the robot is available, a part is moved by the robot to a machine for next operation. Parts are waiting for machines for processing. If a machine is available, a part is processed by the machine. After an operation is finished, the part is checked. If the part does not finish all operations, the part is waiting for the robot for moving. Otherwise, the part is waiting for the L/U to be unloaded. The diagram of the control flow is illustrated in Fig. 2.

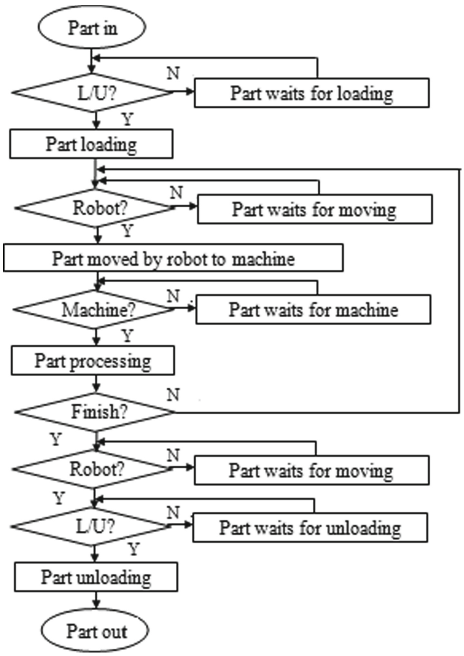

Fig. 2. Control flow of part processing.

4 Conclusion

In contemporary manufacturing and supply chain environments, companies often face challenge in satisfying customers' requirements quickly and accurately at a low price in dynamic and changing environments. Mass customization and integrated decision-making can provide help to companies to overcome the difficulty.

The FMS scheduling problem is part of the FMS production and operation management problem. Because the production management of FMSs is very difficult, the FMS scheduling problem is very complicated. Many researchers have investigated the FMS scheduling problem.

In this paper, the FMS scheduling research with recent development is reviewed. It is summarized as FMS part input sequencing, sequencing and scheduling in FMSs with robot material handling, and machine scheduling with FMS material handling. It is hoped that the review can provide researchers with a reference of the FMS scheduling.

This paper also develops a framework for FMS scheduling integration for mass customization. A control flow of FMS part processing is designed. The integrated scheduler for the FMS scheduling integration can be developed by integrating the FMS part input scheduler, the FMS robot scheduler, and the FMS machine scheduler. It can also be developed by combining the simultaneous scheduler with the FMS machine scheduler.

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