OPTIMIZATION-BASED SIMULATION ALGORITHM FOR PREDICTIVE-REACTIVE JOB-SHOP SCHEDULING OF RECONFIGURABLE MANUFACTURING SYSTEMS

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Faculty of Manufacturing Engineering

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TAN JOE YEE

A thesis submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "Optimization-Based Simulation Algorithm for Predictive-Reactive Job-shop Scheduling of Reconfigurable Manufacturing Systems" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

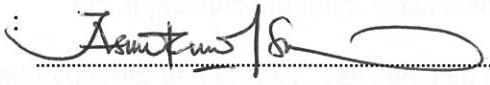
Signature : .....

Name : TAN JOE YEE

Date : 05/11/2022

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

Signature : 

Supervisor Name : IR. DR. -ING. AZRUL AZWAN BIN ABDUL RAHMAN CENG

Date : 05/11/2022

DEDICATION

Only

my beloved father, Tan Chee Kong

my appreciated mother, Chan Kam Ling

my adored sister and brother, Tan Jun Yen and Tan Joe Ven

for giving me moral support, encouragement and also understandings.

ABSTRACT

Manufacturing industry is now moving forward rapidly towards reconfigurability and reliability to meet the hard-to-predict global business market, especially job-shop production. However, even there is a proper planned schedule for production, and there is also technique for scheduling in Reconfigurable Manufacturing System (RMS) but job-shop production will always come out with errors and disruption due to complex and uncertainty happening during the production process, hence fail to fulfill the due-date requirements. This study proposes a generic control strategy for piloting the implementation of a complex scheduling challenge in a RMS. This study is aimed to formulate an optimization-based algorithm with simulation tool to reduce the throughput time of complex RMS, which can comply with complex product allocations and flexible routings of the system. Predictive-reactive strategy was investigated, in which Genetic Algorithm (GA) and dispatching rules were used for predictive scheduling and reactivity controls. This research also provided some results in combining the rule-based simulation with optimization: first, a feasible schedule was computed and then fine-tuned with the rule-based simulation system, then tested with RMS which is the reactive part. Simulation experiments were run using different parameters to analyze the performance of the proposed algorithm with the system. The results showed that the proposed optimization-based algorithm had successfully reduce the throughput time of the system. In this case, the effectiveness and reliability of RMS is increase by combining the simulation with the optimization algorithm.

ALGORITMA SIMULASI BERASASKAN PENGOPTIMUMAN UNTUK RAMALAN-BERTINDAKBALAS PENJADUALAN BENGKEL-KERJA BAGI KONFIGURASI SEMULA SISTEM PEMBUATAN

ABSTRAK

Industri pembuatan sedang menuju ke arah factor konfigurasi semula dan kebolehpercayaan untuk mencapai pasaran perniagaan secara global yang sukar diramalkan, terutamanya pengeluaran secara kerja bengkel. Walaupun jadual pengeluaran telah pun dirancang dan juga teknik penjadualan bagi system pembuatan konfigurasi semula telah dilaksanakan, namun terdapat juga masalah and gangguan yang disebabkan oleh kerumitan dan ketidakpastian dalam process pengeluaran, oleh itu sentiasa melebihi tempoh masa yang dituntukan. Kajian ini mencadangkan strategi kawalan generik untuk merintis pelaksanaan cabaran penjadualan kompleks dalam RMS. Kajian ini bertujuan untuk merumuskan algoritma berasaskan pengoptimuman dengan alat simulasi untuk mengurangkan masa pemprosesan RMS kompleks, dan boleh mematuhi peruntukan produk yang kompleks dan penghalaan yang fleksibel. Strategi ramalan-reaktif telah dianaliskan, di mana Algoritma Genetik (GA) dan peraturan penghantaran digunakan untuk penjadualan ramalan dan kawalan kereaktifan. Penyelidikan ini juga memberikan keputusan dalam menggabungkan simulasi berasaskan peraturan dengan pengoptimuman: yang pertama, jadual yang boleh dilaksanakan telah dikira dan kemudian diperhalusi dengan sistem simulasi berasaskan peraturan, kemudian diuji dengan RMS yang merupakan bahagian reaktif. Eksperimen simulasi dijalankan menggunakan parameter yang berbeza untuk menganalisis prestasi algoritma yang dicadangkan. Keputusan menunjukkan bahawa algoritma berasaskan pengoptimuman yang dicadangkan telah berjaya mengurangkan masa pemprosesan sistem. Dalam kes ini, keberkesanan dan kebolehpercayaan RMS meningkat dengan menggabungkan simulasi dengan algoritma pengoptimuman.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI	-	Artificial Intelligence
dd	-	Day
DML	-	Dedicated Manufacturing Line
EA	-	Evolutionary algorithm
FMS	-	Flexible Manufacturing System
GA	-	Genetic Algorithm
JSS	-	Job-shop scheduling
Lv	-	Level
min	-	Minute
mm	-	Month
NP	-	Non-deterministic Polynomial-time
Op	-	Option
OX	-	Order crossover
PMX	-	Partially matched crossover
RGV	-	Rail Guided Vehicle
RMS	-	Reconfigurable Manufacturing System
SBO	-	Simulation-based optimization
UI	-	User Interface
VDI	-	Verein Deutscher Ingenieure
yy	-	Year

LIST OF APPENDICES

LIST OF PUBLICATIONS

Indexed Journal

Tan, J. Y., Abdul Rahman, A. A., Arfauz, A. R., Salleh, M. R. and Bilge, P., 2020. Predictive-reactive Job-shop Scheduling for Flexible Production Systems with the Combination of Optimization and Simulation Based Algorithm. *Journal of Advanced Manufacturing Technology,* 14(3), pp. 81-93.

Tan, J. Y., Abdul Rahman, A. A., Nadiah, A. and Arfauz, A. R., 2021. The Effect of Lateral Lifting Tasks on Hand Grip and Pinch Strength Measurements. *IIUM Engineering Journal*, 22(2), pp. 261-282.

CHAPTER 1

INTRODUCTION

1.1 Background

The contemporary market continues to drive all kinds of companies and businesses, particularly manufacturers, towards flexibility. However, the random input orders and non-standardized manufacturing methods, along with the growing number of goods and variations causes current manufacturing systems to become more complex (Asadzadeh, 2015; Niehues et al., 2015; Allahverdi et al., 2018). The complexity and limitations of manufacturing processes causes the products throughput time has greatly increase and unable to achieve due date requirements (Scholz-Reiter et al., 2015). Manufacturing sectors are forced to handle demand fluctuations, rapidly adopt new products and order changes to make sure that the products are finished a within specific time (Angkiriwang et al., 2014).

The first moving assembly line which invented by Henry Ford was installed at the Ford Highland Park plant in Michigan, the origin of notable inventions in manufacturing. The Ford Windsor Engine Plant was designed and built in 1998–2000, which contains total of 120 CNC machines which are arranged in a reconfigurable system architecture that consists of 20 stages (6 machines per stage). Ford Motor Co. called this system as Flexible, Reconfigurable Manufacturing System, where flexible is referred to the CNC machines in this system can produce multiple product variants. Koren (2014) is the first who researched on Reconfigurable Manufacturing System (RMS), and have proved that RMS is useful in this situation. RMS can imbibe newer technologies in the production process and an

optimally designed RMS has the capacity of DMS and functionality of FMS built into one single system as shown in Figure 1.1 as below (Singh et al., 2017).

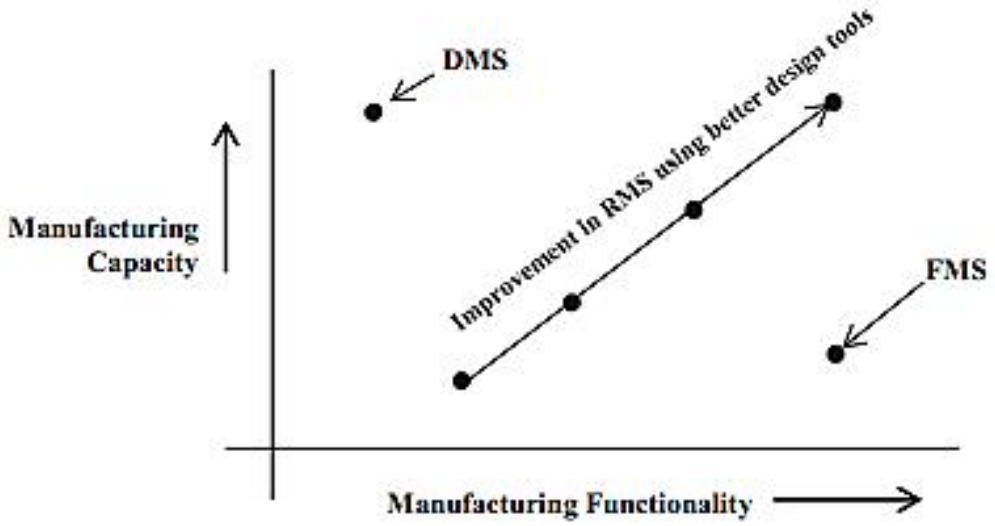

Figure 1.1 RMS dual functionality of dedicated manufacturing system and flexible manufacturing system (Koren et.al., 2017).

RMS is quite common in recent research works, and most algorithms, dispatching rules, and strategies have already been developed with RMS, but majority of studies in job scheduling concentrate on static scheduling constraints and not consider dynamic factors (Kundakci and Kulak, 2016). Conventional approaches suggest a high approximation of real systems and are complex in formulation; indeed, due to the complexity of the large number of variables and restrictions, most of the current algorithms do not give good result in a reasonable time (Nehzati, 2012; Choi and Xirouchakis, 2015; Wan and Yan, 2015; Niehues et al., 2016; Nasiri et al., 2017).

According to research, the predictive-reactive approach can adapted to rapid changes of shop floor's execution and provide a flexible schedule (Tang and Wang, 2008). While since it is very difficult to perform optimization process analytically during such complicated processes, simulation-based optimization is also useful in this scenario (Korytkowski et al., 2013). On the other hand, scheduling and controlling with simulation-

based optimization can increase the performance and efficiency of the output manufacturing systems, provide easy and fast evaluation of new layouts and schedules with direct production control (Fera et al., 2013; Doh et al., 2016; Leusin et al., 2018; Niehues et al., 2018b).

Due to dynamic job-shop scheduling problems are NP-hard combinatorial optimization problems, heuristic methods are useful for solving these types of problems (Kundakci and Kulak, 2016). Hence, this research focuses on modelling the simulation model for RMS that can provide versatility in system layout and product mix with flexible routing and production sequence, which is especially useful during the mass customization process in manufacturing industry.

The combination of simulation and optimization-based algorithm with the predictive-reactive approach for scheduling of the RMS under various optimization restrictions were studied through experiments. For the predictive part, the feasible schedule for RMS job-shop is predicted and decided. Rule-based simulation and optimization is then implemented into the schedule: first, a rough schedule was determined using optimization algorithm, then rule-based simulation systems were used to refine the schedule to obtain the most optimal results. For the reactive phase, the schedule obtained is adjusted and validated by MONTRAC monorail system. The results obtained from the experiments is compared and analysed to find out the effectivity of the proposed method structure, algorithms and architecture.

1.2 Problem Statement

The RMS are getting more complex and facing more challenges due to the new evolution of market demands, causing the processing time for a product has increased and the products cannot complete on schedule, especially in job-shop productions (Allahverdi