UNIVERSITI PUTRA MALAYSIA

HYBRID DYNAMIC SCHEDULING MODEL FOR FLEXIBLE MANUFACTURING SYSTEM WITH MACHINE AVAILABILITY AND NEW JOB ARRIVALS

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By

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Scheduling problem in flexible manufacturing system (FMS) is considered dynamic since new orders arrival and machine breakdowns may inevitably render the current schedule inapplicable. This makes rescheduling necessary to instantly handle machine breakdown and accommodate the new arriving orders into the existing schedule while maintaining the efficiency and stability of the current schedule. However, frequent rescheduling may lead to instability and lack of continuity in the existing shop floor schedules. Therefore, this research aims to propose an effective and practical scheduling/rescheduling approach that takes into account the real FMS environment and the desired objectives of manufacturing systems. The proposed approach provides high quality solution with respect to efficiency as well as shop floor stability. The idea of hybridizing the newly developed biogeography based optimization algorithm (BBO) with variable neighborhood structure (VNS) is proposed in order to produce a high performance initial schedule in terms of minimum completion time, tardiness and flow time within reasonable amount of time. Furthermore, due to the limitation of single rescheduling strategy to handle various disruptions, an approach that combines multiple rescheduling strategy is used to maintain efficiency and stability. The hybrid rescheduling strategy takes into account the affected operation rescheduling (AOR) strategy and BBO-VNS match-up approaches to handle machine breakdown and accommodates new arrived order without changing the sequence of operations on machines. The BBO-VNS match-up algorithm manipulates the idle times on machines within the time horizon for assigning the affected operations by breakdown and/or newly arrived orders. Subsequently, a novel approach that combines the hybrid rescheduling strategy with an initial robust schedule which is generated using random fuzzy variables is presented. The aim is to associate an effective hybrid dynamic scheduling model that is able to facilitate the control and accommodation of future disruptions. The performance of the schedules as produced by the scheduling/rescheduling algorithms were investigated and compared. The proposed approaches have been successfully tested on the benchmark test problems and verified in the real FMS scheduling environment based on tardiness and flow time and stability. The statistical analyses demonstrate the efficiency and effectiveness of the proposed hybrid BBO-VNS algorithm over GA, BBO and PBSA to find optimum/near optimum solutions within reasonable amount of time.

In addition, the experimental results illustrate the effectiveness of hybrid rescheduling strategy for handling complex disruptions, in which schedules with high quality stable are produced. On average, the hybrid rescheduling approach improves the performance with respect to both the average efficiency measure (AEM) and average stability measure (ASM) obtained under total rescheduling (TR) by 17.07%, AOR by 5.58%, route change rescheduling (RCR) by 9.75%, right-shift rescheduling (RSR) by 25.50% and BBO-VNS match-up by 4.01%. Furthermore, the results of combined hybrid rescheduling strategy with initial robust schedule in presence of multiple disruptions confirmed that their combination is effective in which even more reliable high quality stable schedules are delivered in which the combined approach achieves significant improvement over hybrid rescheduling strategy based on the initial predictive schedule strategy is 5.13%, over modified AOR is 16.19% and over TR is 19.43% with respect to the mean of efficiency and stability. Therefore, the experimental results have favorably shown that the proposed improved hybrid dynamic scheduling is effective and practical in providing reliable solutions in a real world dynamic and uncertain FMS with respect to desired objectives of manufacturing system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

HYBRID DYNAMIC PENJADUALAN MODEL UNTUK SISTEM PEMBUATAN FLEKSIBEL DENGAN MESIN KESEDIAAN DAN PESANAN BARU

Oleh

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Masalah penjadualan dalam sistem pembuatan fleksibel (FMS) dianggap dinamik kerana ketibaan pesanan baru dan kerosakan mesin tidak memberikan gambaran prestasi jadual yang sedia ada. Disebabkan oleh masalah ini, penjadualan semula perlu dibuat dengan segera bagi mengendalikan kerosakan mesin dan menampung pesanan baru ke dalam jadual yang sedia ada di samping mengekalkan kecekapan semasa dan kestabilan jadual. Walau bagaimanapun, penjadualan semula yang kerap boleh membawa kepada ketidakstabilan dan kekurangan kesinambungan dalam jadual yang sedia ada. Oleh itu, kajian ini bertujuan untuk mencadangkan satu penjadualan yang berkesan dan praktikal / pendekatan penjadualan yang mengambil kira persekitaran FMS sebenar dan objektif yang dikehendaki melalui sistem pembuatan. Pendekatan yang dicadangkan menyediakan penyelesaian berkualiti tinggi berserta dengan kecekapan serta kestabilan kawasan kerja. Idea penggabungan algoritma baru dibangunkan berasaskan biogeografi pengoptimuman algoritma (BBO) dengan struktur pengubah kejiranan (VNS) dicadangkan untuk menghasilkan jadual prestasi tinggi awal dalam jangkamasa yang munasabah. Tambahan pula, disebabkan oleh had strategi penjadualan tunggal, satu pendekatan untuk menangani pelbagai gangguan yang menggabungkan strategi penjadualan semula, digunakan untuk mengekalkan kecekapan dan kestabilan. Strategi penjadualan gabungan mengambil kira, operasi penjadualan yang terjejas (AOR) strategi dan pendekatan pemadanan BBO-VNS untuk menangani kerosakan mesin dan menempatkan pesanan yang baru tiba tanpa mengubah urutan operasi pada mesin. Padanan algoritma BBO-VNS memanipulasi masa terbiar terdapat pada tetingkap masa mesin, dengan memasukkan operasi yang terjejas oleh kerosakan dan / atau pesanan yang baru tiba. Selepas itu, satu pendekatan baru yang menggabungkan strategi penjadualan gabungan dengan jadual awal yang tepat dijana menggunakan pembolehubah kabur rawak. Tujuannya adalah untuk mengaitkan model gabungan penjadualan dinamik berkesan yang mampu memudahkan kawalan dan penyesuaian gangguan di masa depan. Prestasi jadual seperti yang dihasilkan oleh penjadualan / penjadualan semula algoritma telah diselidik dan dibandingkan. Pendekatan yang dicadangkan telah berjaya diuji dengan rumusan ujian penanda aras dan disahkan dalam persekitaran penjadualan FMS yang sebenar berdasarkan kepada pengalaman dan aliran masa dan kestabilan. Analisis statistik menunjukkan kecekapan dan keberkesanan

algoritma hibrid BBO-VNS yang dicadangkan atas GA, BBO dan PBSA untuk mencari penyelesaian yang optimum penyelesaian yang hampir optimum dalam jumlah munasabah. Di samping itu, keputusan eksperimen menunjukkan keberkesanan strategi penjadualan gabungan untuk menyelesaikan gangguan kompleks, di mana jadual dengan kualiti yang tinggi dan stabil dapat dihasilkan. Rata-rata, pendekatan penjadualan semula hibrid meningkatkan prestasi berkenaan dengan kedua-dua ukuran kecekapan purata (AEM) dan purata ukuran kestabilan (ASM) yang diperolehi di bawah jumlah penjadualan semula (TR) dengan kadar 17.07%, AOR dengan kadar 5.58%, perubahan kekalahan penjadualan semula (RCR) dengan kadar 9.75%, penjadualan semula syif-betul (RSR) dengan kadar 25.50% dan padanan BBO-VNS raih sebanyak 4.01%. Tambahan pula, hasil gabungan hibrid strategi penjadualan semula jadual teguh awal dalam kehadiran pelbagai gangguan mengesahkan bahawa gabungan mereka adalah berkesan di mana jadual stabil walaupun lebih dipercayai berkualiti tinggi, dihantar dan di mana pendekatan yang digabungkan mencapai peningkatan yang ketara berbanding strategi penjadualan semula hibrid berdasarkan strategi jadual ramalan awal iaitu 5.13%, AOR lebih diubahsuai adalah 16.19% dan lebih TR adalah 19.43% berdasarkan min kecekapan dan kestabilan. Oleh itu, keputusan eksperimen telah menggalakkan menunjukkan bahawa hibrid meningkat penjadualan dinamik yang dicadangkan untuk menjadi berkesan dan praktikal dalam menyediakan penyelesaian yang boleh dipercayai dalam dunia yang sebenar FMS dinamik dan tidak menentu berkenaan dengan objektif yang dikehendaki sistem pembuatan.

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LIST OF ABBREVIATIONS

AOR	Affected operation rescheduling
ARPD	Average relative percentage deviation
BBO	Biogeography based optimization
CNC	Computer numerical control
Ef	Efficiency
FJSP	Flexible job shop scheduling problem
FMS	Flexible manufacturing system
FMT	Flexible manufacturing technology
GA	Genetic algorithm
HSI	Habitat suitability index
Hybrid	Hybrid AOR and BBO-VNS match-up algorithm
Hybrid-R	Robust schedule combined with hybrid AOR and BBO-VNS match-up algorithm
IPOX	Improved precedence operation crossover
JSP	Job shop scheduling problem
mAOR	Modified affected operation rescheduling
MILP	Mixed integer linear programming
MK	Makespan
MPX	Multipoint preservative crossover
Nec	Necessity
NS	Neighborhood structure
PBSA	Population based simulated annealing
Pos	Possibility
RCR	Route change rescheduling
RPD	Relative percentage deviation
RSR	Right shift rescheduling
SG	Satisfaction grade
SIV	Suitability index variable
St	Stability
TR	Total rescheduling
TWFQT	Total weighted quadratic tardiness
TWFT	Total weighted flow time
VNS	Variable neighborhood search
WIP	Work-in-progress

LIST OF SYMBOLS

j	Job/Part
O	Operation
k	Machine
P	Processing time
t	Tool
λ	Immigration rate
μ	Emigration rate
ψ	Mean SG in term of efficiency
Z	Mean SG in terms efficiency and stability

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CHAPTER 1

INTRODUCTION

1.1 Background

Flexible manufacturing systems (FMSs) are known as complex production systems to efficiently respond to the current market issues. These issues can be: (i) shorten the manufacturing lead time to fulfil customers need, (ii) flexibility to adopt the market changes; and (iii) increase productivity and decrease production costs to retain the market share (Atmani & Lashkari, 1998). FMSs are defined as integrated systems consisting of computer numerical control (CNC) machines linked by automated material handling mechanisms. They combine the flexibility of a job shop and the efficiency of flow line to best suit the batch production of mid-volume and mid-variety products.

Because of these properties and highly intensive capital required for their implementation, FMS has gained worldwide attention in recent years. One feature of such manufacturing systems which is mostly difficult in practice is scheduling. Scheduling is associated with determining when and employing what resources for the jobs to be accomplished in the shop floor when these jobs are competing for the same resources with limited availability. It should also be noted that a static availability of resources is never exist in a real manufacturing system.

Generally, the scheduling environment can be classified into two main categories: static and dynamic. In a static environment all job are available and ready for processing. Once the scheduling is prepared, the processing sequence is determined and is not changed during processing. On the other hand, in a dynamic scheduling environment, unforeseen disruptions such as machine breakdown, new job arrivals or job cancellation prevent the execution of production schedules as they are developed (Zhang et al., 2013b).

The main difference between static and dynamic scheduling lies in the robustness and in the response reactivity of the algorithm to perturbation introduced into the manufacturing system (Kumar et al., 2011). Unfortunately, most manufacturing environment systems operate in dynamic environment subject to various real-time events, which may render the predictive optimal schedule neither feasible or nor optimal (Subramaniam & Raheja, 2003). This makes rescheduling necessary to respond to the disturbances and to improve the efficiency of the disturbed FMS.

Rescheduling is a process of generating an executable schedule upon the occurrence of an unforeseen disruption. Because a schedule is subject to disruptions, the importance of rescheduling is comparable with that of scheduling. On the other hand, rescheduling needs to generate an efficient schedule quickly and reflect the characteristics of the original schedule (Abumaizar & Svestka, 1997). Two important criteria must be considered when evaluating a rescheduling strategy: (i) the efficiency of the resultant schedule, which is measured with the same objective functions used to evaluate the initial schedule and (ii) stability of the resultant schedule, which refers to how closely the new schedule resembles the initial one (Moratori et al., 2008). Therefore, the aim of efficiency is to minimize the size of inventory, work-in-progress (WIP), as well as ensuring that all of the orders meet their due dates. Meanwhile the stability aims on keeping the original starting time, sequence and machine of the current schedule as much as possible accommodating disruptions. The stability is crucial especially for the FMS that involves costly equipment and materials in their production because any deviation to the original plan may lead to increased production costs.

Although over the past years scheduling problems have been extensively studied, including scheduling in static and dynamic environments, earlier literature have shown that the conventional scheduling theories have gained little attention in real manufacturing systems (Aytug et al., 2005). The inability of much scheduling research to address the general issue of uncertainty, assuming static environment, is often cited as a major reason for the lack of influence of scheduling research on industrial practice. According to recent studies, this is never present a real scenario in many manufacturing systems (Kumar et al., 2011; Sabuncuoglu & Goren, 2009; Shi-jin et al., 2007; Zakaria & Petrovic, 2012). In fact, initial schedules must be revised frequently to stay feasible and practical in response to unexpected changes taking place in production environments (Ouelhadj & Petrovic, 2009; Vieira et al., 2003).

Research on dynamic scheduling has been attracting attention, in which new optimization models and different techniques are proposed, evaluated and employed to manage uncertain environments (Ouelhadj & Petrovic, 2009). To derive better dynamic scheduling systems, some researchers developed hybrid approaches which combine various techniques and strategies to tackle the uncertainties (He & Sun, 2013; Zhang et al., 2013b).

1.2 Problem Statement

FMSs are recognized by the use of computer control system in place of the hard automation usually appeared in transfer lines. This enables FMSs to configure very quickly to produce various parts, while also maintaining some of the manufacturing efficiencies otherwise lost in a job shop type of setting. This duality of objectives makes the management of an FMS complex (Nagarjuna et al., 2006). The physical characteristics of actual manufacturing systems and severe market requirements introduce more constraints than opportunities when formulation and solution of a scheduling problem is pursued (Zeballos, 2010). Scheduling and control problems of FMSs are more difficult than those of mass production system due to the access to alternative resources results in routing flexibility (Gamila & Motavalli, 2003). Moreover, FMS scheduling problem have to consider additional constraints on resources such as storage, transport devices, and tool change facilities. These factors make FMS scheduling more complex than in classical scheduling problem.

As pointed by Low et al. (2006) production scheduling can be preserved as four subproblems: (i) part type selection, (ii) machine loading, (iii) part sequencing, and (iv) operation scheduling. In fact, most of scheduling problems are NP-hard combinatorial optimization problems, i.e., the time required to solve the problem optimally increase exponentially with increasing problem size (Gamila & Motavalli, 2003; Goren & Sabuncuoglu, 2009).

The first challenge of FMS scheduling comes from having an integrated approach to consider several features found in the industrial environment, such as due dates of parts, limits on tool magazine, as well as machining cost and different problems such as tool allocation, machine loading, part routing as well as task timing of operations (Gamila & Motavalli, 2003; Özpeynirci, 2015; Zeballos, 2010). Due to the combinatorial complexity of this challenge, most researchers adopt assumptions that aim at making it tractable. Therefore, a proper approach is required to clearly specify the key parameters and their influences on the scheduling problem (Abazari et al., 2012).

Since FMS scheduling may comprise ten to hundreds of machines and various part types to be scheduled over a period varying from weeks to several months, the size of the scheduling problem makes some of the proposed approaches by scheduling research to be impractical. Thus, there is a need for a practical scheduling approach that integrates various factors and problems to obtain not necessarily optimal, but rather near optimal solution within reasonable amount of time (Arikan & Erol, 2012; Baruwa & Piera, 2014; Huang et al., 2014; Low et al., 2006).

The challenges in real-time decision making differ from the static planning tasks in a number of aspects. The most important difference is that dynamic scheduling needs to deal with unexpected events as the environment has. The two most popular and challenging disturbances that call for rescheduling in FMS are: machine breakdown and new order arrival (Sun et al., 2014). In order to accommodate these disruptions, dynamic scheduling approaches such as online schedule, predictive-reactive scheduling and proactive-reactive scheduling are needed to keep the original schedule efficient and stable (Ouelhadj & Petrovic, 2009).

Moreover, the impacts of handling the machine breakdowns and accommodating new order arrivals are unpredictable to the efficiency and stability of the original schedule and are often dependent on several parameters such as size of disruption, time of occurrence of the disruption and size of original schedule (Subramaniam & Raheja, 2003).

In addition to occurrence of unexpected events, real-time decisions must be made within a tight time frame. Because of this, the well-studied intelligent method such as evolutionary algorithms which can often outperform conventional optimization methods when applied to difficult real-world problem can be used (Al-Hinai & Elmekkawy, 2011; Simon, 2008; Wang et al., 2013). This is due to their ability to mimic the whole problem to be solved, and to easily absorb the variability of FMS parameters and constraints in representing the real problem.

Therefore, literature as well as recent feedback from industrial collaborators have shown that presently the most desired scheduling approach is the one that considers all the above mentioned challenges at best (Gomes et al., 2010).

In order to deal with the challenges faced by scheduling of current FMS industries and their requirements to rapidly accommodate the impact of disturbances such as machine availability and new orders arrival into the initial production schedule, an effective and practical approach needs to be taken into account. The approach should be capable to achieve a high quality schedule in order to preserve the efficiency and the stability of the existing schedule when machine available for a period of time and new order arrives. Hence, the main research question is:

How to effectively and practically handle dynamic scheduling problem of FMS in presence of machine breakdowns and new orders arrival?

Therefore, the following issues will be taken into account to solve the dynamic scheduling problem:

1. How to solve the FMS scheduling problem that concerns with various decisions and different constraints by using an effective method?
2. How to develop an effective dynamic scheduling (rescheduling) strategy in presence of machine availability and new order arrivals?
3. How to improve and verify the developed approach in terms of efficiency and stability?
4. How to validate the developed approach?

1.3 Research Goals and Objectives

The goal of this study is to propose a hybrid, effective and practical approach for FMS dynamic scheduling problem. In order to be hybrid, it has to consider the integration of different strategies to overcome the limitation of single strategy which cannot easily guarantee efficiency and stability. In order to be effective, it has to provide a solution not only with respect to efficiency to produce a good quality solution, but also stability to reduce the number of changes after rescheduling. In order to be practical, it has to be able to generate an acceptable schedule that is applicable in real FMS environment. It is expected that the goal of this research is to be achieved through the following objectives:

1. To develop a mathematical model and a new optimization algorithm to solve the FMS static scheduling problem (by analyzing various algorithms) and a new hybrid rescheduling strategy to solve FMS dynamic scheduling problem.
2. To improve the dynamic scheduling model in order to enhance the performance of scheduling with respect to efficiency and stability and verify the developed dynamic scheduling model.
3. To validate the developed dynamic scheduling model by implementing in real FMS environment.

1.4 Research Scopes and Significance

Since FMS scheduling comprises some different level of flexibilities, various decisions, constraints, and uncertainties that make the problem more complicated, some scopes and limitations have been considered to make it tractable. This research will focus within the following limitations:

1. This study takes into account only discrete manufacturing system in which the product is characterized as unit production or part production.
2. This research uses mathematical model only for specifying the key parameters and their influences on the static scheduling problem.
3. This study only considers routing flexibility in which operation(s) of a part can be executed through alternative machines, but does not take into account operation flexibility, machine flexibility and sequence flexibility.
4. This study only considers two of the most common disruptions often occurring in manufacturing system, machine availability and new job

arrivals, with assumptions that the information of processing time and due date of all operations are determined in advance. The newly arrived order and machine availability problem are enough to be considered hard when involving the large number of machines and jobs in real FMS environment with variable scheduling parameters.

5. This study does not consider the static analysis validation.

Most research reported in the literature concentrates on optimizing a certain objective functions under idealized conditions and thus do not take into account system disruptions. This study is considered significant as it tends to solve dynamic scheduling problem due to the machines breakdown and the arrival of new orders that commonly occur in all production systems. The mathematical model can take into consideration several features found in industrial environments not only for specifying the key parameters and their influence, but also formulates the problem and provides insights to capture the potential for significant manufacturing productivity improvement. In turn, the proposed hybrid BBO-VNS algorithm can be used as a useful solution for optimization in various industries application within reasonable computational time. Furthermore, the proposed hybrid rescheduling strategy that manages to handle machine availability and accommodate new orders to minimize the number of deviations in the schedule offers a promising approach to the decision makers to overcome shop floor nervousness. In addition, using a combination of the proposed hybrid rescheduling strategy with the initial robust schedule can facilitate the handling of future disruptions and improve the robustness and stability of the initial schedule.

The proposed dynamic scheduling model can lead to applications in production environments that can be modeled as a flexible job shop and flexible manufacturing system. First, the proposed BBO-VNS algorithm is used to create initial proactive schedule based on the information regarding machine availability. During execution of initial schedule, all information about manufacturing system (like the information about existing machines, the newly arrived orders and other required information) as well as shop floor status are required to be updated at every point in time. Then, the proposed hybrid BBO-VNS match-up algorithm is implemented when a rescheduling is triggered.

The performance measures considered in this study are concern about the level of WIP and inventory, and the customer satisfaction which is also one of the aims of modern manufacturing such as lean production system to improve the quality, and reduce the production time and cost. Therefore, the success of this study may support towards the betterment of lean manufacturing performance. The improvement can be achieved through the minimum maximum completion time, minimum flow time (waiting time), and minimum tardiness (level of work in process and inventory).

1.5 Summary of Thesis Contributions

The main contribution of this study is the introduction of a new hybrid BBO-VNS algorithm to solve FMS scheduling problem. Moreover, a hybrid rescheduling strategy is developed to manage dynamic scheduling problem in presence of machine availability and new job arrivals in a complex real world FMS. In addition, a novel approach that integrate rescheduling strategies with initial robust schedules is also proposed and validated. The proposed approaches are described in the following chapters:

1. Chapter 4 describes the proposed new hybrid BBO-VNS algorithm to solve FMS static scheduling problem when several scheduling decisions with different constraints are taken into account.
2. Chapter 4 considers the hybrid rescheduling strategy that manages to handle machine availability and new order(s) arrival with minimum number of deviations to the existing schedule to overcome shop floor nervousness and improve the FMS performance
3. Chapter 5 introduces a new approach to combine the proposed hybrid rescheduling strategy with the producing of initial schedule. Fuzzy random distribution is employed to generate this schedule, in which recorded data provides information. The goal is to facilitate the handling of future disruptions by inserting idle timeslots on machine and, subsequently generate more reliable and effective solutions for the manufacturing system.
4. Chapter 6 describes the ability of proposed approach to manage disruptions in a complex real FMS.

1.6 Structure of Thesis

This thesis is organized into 8 chapters. Brief descriptions of the contents of each chapter are given as follows:

1. This thesis begins with discussions on some problem background, goal, objectives, limitations and contributions of this research as features in Chapter 1.
2. Chapter 2 presents a review of some background and related works in this area that forms the basis of this study.
3. Chapter 3 describes the research methodology used in the study including research design, data sets, instrumentations, problem description, experiments and analysis and performance measures considered in this research.
4. Chapter 4 develops a mathematical model to clearly specify the FMS scheduling parameters and constraints to formulate the problem. Moreover, a new evolutionary algorithm, called hybrid BBO-VNS, is proposed to solve the FMS scheduling problem to produce the initial schedule. Moreover, a hybrid strategy to react to the problem of dynamic FMS scheduling in presence of uncertainties such as machine breakdown and new orders arrival is studied. This chapter first considers different rescheduling strategies based on the size of disruptions to handle machine breakdown and then a match-up repair strategy is presented to accommodate new orders into the schedule.
5. Chapter 5 discusses a novel approach that combines the hybrid rescheduling strategy with initial robust schedule based on the random fuzzy variable. This scheduling system inserts idle timeslots on machine based on imprecise and/or incomplete recorded date. The aim is to produce initial robust (proactive) schedule that is able to facilitate the handling of the machine availability and newly arriving orders.
6. Chapter 6 delivers an implementation of proactive-reactive scheduling approach to the real FMS.
7. Chapter 7 concludes the findings, contributions and possible future works to be conducted as derived from this study.

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