DEADLOCK DETECTION AND AVOIDANCE IN FMS WITH SHARED RESOURCES AND PARALLEL MACHINES USING PETRI NET

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Manufacturing Engineering)

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ABSTRACT

Deadlock is a critical case in flexible manufacturing system that results from concurrency and resource sharing for processing different types of parts. It leads to less efficiency and fewer parts to be produced. Previous attempts to solve this issue focused on putting constraints on process flow of a simple system to avoid deadlock. Yet, this way reduces the performance of system and hence the number of final products. Besides, it does not ensure its capability in complex systems. Thus, the objective of this dissertation is to model and simulate complex flexible manufacturing system of industrial company that has shared resource and parallel machines using timed colored petri net. It also aims to analyse the system in terms of utilization in each stage and detect the deadlock where high utilization is found. Another objective is to avoid the deadlocks that have effect on the daily production of the system. The manufacturing system was modelled and simulated using CPN tool. Then, the analysis of the simulation in CPN was performed. It showed that deadlock exists in wire straightening with 88.55%, injection trolley 3 with 86.392%, spinning machine 1_2 with 90.611% and spinning machine 1_3 with 82.311% utilization. Four boilers and mould revolution were also determined as deadlocks having 87.75% and 98.295% utilization respectively. Deadlock avoidance was then conducted through testing six plans in the manufacturing system to improve the daily production of the company. It was concluded that the best one is by adding another resource in wire straightening, injection trolley 3 and mould revolution stages. The simulation in CPN showed that this plan can achieve 22.047% increase in production. The utilization in the three deadlocks became in between 55% to 60%. This method for detecting and avoiding deadlock was validated in Delmia Quest and the simulation of improvement showed that the suggested plan will improve the current production by 22.134% increase.

خلاصة البحث

الجمود هو حالة حرجة في نظام التصنيع المرن الذي ينجم عن التزامن وتقاسم الموارد لمعالجة أنواع مختلفة من القطع. هذا يؤدي إلى أقل كفاءة وعدد أقل من الأجزاء التي يتم إنتاجها. تركزت المحاولات السابقة لحل هذه المسألة على وضع قيود في تدفق عمليات نظامٍ بسيطٍ لتفادي الجمود. مع ذلك، تقلل هذه الطريقة من أداء النظام وبالتالي عدد المنتجات النهائية. إلى جانب ذلك، فإنها لا تضمن مقدرتها في النظم المعقدة. وبالتالي، فإن الهدف من هذه الرسالة هو محاكاة نظام التصنيع المرن والمعقد لشركة صناعية تمتلك موارد مشتركة وأجهزة موازية باستخدام شبكة بتري الملونة والمحتوية على الوقت. كما تهدف إلى تحليل النظام من حيث الاستخدام في كل مرحلة وكشف الجمود حيث وجود الاستخدام العالي. الهدف الآخر هو لتجنب المآزق التي لها تأثير على الإنتاج اليومي للنظام. تم محاكاة نظام التصنيع باستخدام أداة CPN. بعد ذلك، تم إجراء تحليل للمحاكاة في CPN. بيّن التحليل أن الجمود موجود في استقامة السلك بنسبة 88.55%، عربة الحقن 3 بنسبة 86.392%، آلة الدوران 2_1 بنسبة 90.611%، وآلة الدوران 3_1 بنسبة 82.311% من الاستخدام. تم تحديد أربع آلات غليان وثورة القالب على أنهم أيضاً بحالة جمود بنسبة 87.75% و 98.295% من الاستخدام على التوالي. ثم أُجري تجنب الجمود من خلال اختبار ستة خطط في نظام التصنيع لتحسين الإنتاج اليومي للشركة. خلص الاختبار إلى أن أفضل واحد هو بإضافة مورد آخر في مرحلة استقامة السلك، عربة الحقن 3 وثورة القالب. أظهرت المحاكاة في CPN أن هذه الخطة يمكن أن تحقق 22.047% زيادة في الإنتاج. أصبح الاستخدام في المآزق الثلاثة ما بين نسبة 55% إلى 60%. تم التحقق من صحة هذه الطريقة للكشف عن الجمود وتجنبه في Delmia Quest وأظهرت محاكاة التحسين أن الخطة المقترحة سوف تحسن الإنتاج الحالي بزيادة نسبتها 22.134%.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Manufacturing Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Assem Hatem Taha

Signature……………………. Date …..

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I dedicate this research work to my beloved parents, siblings and my respected supervisors.

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LIST OF SYMBOLS

$\sum$	Color set
A	A set of arcs
B	Boolean
C	Color function
e	Event
E	Expression for arc
G	Guard function
F	Arc
I	Initialization function
k	Token
K(p)	Capacity
N	Node
m	Meter
M	Marking
MS	Multi-Set
P	Place
S	Set of places
T	Transition
W	Weight of arc $\sum$
Z^+	Number of integers

LIST OF ABBREVIATIONS

AMS	Automated Manufacturing System
CNC	Computer Numerically Controlled
CPN	Colored Petri Net
FAS	Flexible Assembly System
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
PN	Petri Net
ROPN	Resource Oriented Petri Net
SMC	Single Machine Cell

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

The competition in marketplace requires companies to be efficient and fast in production. Companies try to have suitable manufacturing systems that can be flexible with any improvement as product life cycle is continuously aimed to be reduced. To respond to these demands, the use of a Flexible Manufacturing System (FMS) has been widely applied in order to attain high production rate and production flexibility (Kaschel & Bernal, 2006).

FMS has capability to react to any changed condition happen in process and product type. Industrial companies use FMS to fulfill the demands for making different kinds of products from small to medium quantity in production (Qiao, Lu, & McLean, 2006). FMS includes both material handling devices and machines controlled by computer programs to make the process flows flexibly. It gives operators the chance to run the tasks simply when it is necessary to manufacture different kinds of products. FMS helps managers to provide customized products, improve equipment utilization to reduce costs and process time (Heizer & Render, 2005).

Manufacturing process has been improved recently in order to meet the increasing requirements of the market. One of the very demanding requirements that impacts the development of the manufacturing process is the variability aspect in the market. Market needs are changing rapidly, which require more flexibility in the manufacturing process to respond to such changes quickly. One of the main criteria that indicates to the flexibility in the manufacturing process is the degree of resources sharing. High degree of resources sharing leads to more flexibility in the production. However, higher degree of resources sharing is also a source of conflicts in accessing the resources by many production processes. This may cause a major issue that industries face in FMS which is deadlock. Deadlock is an event where the manufacturing system wholly or partially is unable to finish tasks. It occurs when some parts in waiting status as the machines needed to complete their operation, are held by other parts in the production line (Xing, Lin, & Hu, 2001).

Deadlock issue was ignored in the past by eliminating all parts or some of them that have a role for the deadlock to happen and using their resource with other parts in the operation. Yet, flexible manufacturing system forced manufacturers to look for ways to allocate resources without deadlock existence to run the operations efficiently, flexibly and at low cost (Fanti & Zhou, 2004). Consequently, there is a need to study deadlock and find a method to detect and avoid it to make the processes work smoothly.

1.2 PURPOSE OF THE STUDY

This study aims to provide a model that helps manufacturers to improve their production lines that have low efficiency. The primary purpose of this work is to model, simulate and analyse a current manufacturing system that has shared resources to propose a model that locates where deadlock occurs and obviates it through better resource allocation. It is expected that this research will help industries to run their manufacturing process more efficiently to increase their production rate.

1.3 PROBLEM STATEMENT

The investigations in the Flexible Manufacturing Systems (FMS) got significant attention recently due to many advantages such as concurrency and resource sharing. FMS usually has parallel jobs with multiple resource sharing. These two situations are common in flexible manufacturing systems. However, inappropriate sharing of the resources or improper resource allocation logic may lead to deadlock occurrence due to the complexity of assigning shared resources to process different part types in an efficient way. Deadlock is an undesirable situation in an automated and semi-automated FMS that has effect on the flexibility of the process flow. Deadlocks types are classified into four main categories: mutual exclusion condition, hold and wait condition, no preemption condition and circular-wait condition. Circular wait condition is the common one among them and can be avoided based on proper resource allocation in the system. The deadlock and blocking phenomena may lead to tragic results. Detecting and avoiding deadlocks in the manufacturing systems through developing simulating model will improve and increase the efficiency of the flexible manufacturing systems. This research was conducted to develop a model for deadlock detection and avoidance in FMS that has parallel machines with shared resources. Timed colored petri net was used to handle the deadlock problem in order to improve the manufacturing process performance by enhancing resources allocation and making sure that processes complete their tasks successfully.

1.4 RESEARCH OBJECTIVES

Certain objectives were to be achieved for this research. These objectives are as follows:

1. To study and analyse flexible manufacturing system, deadlocks that may happen and petri net.
2. To model and simulate flexible manufacturing system with shared resources and parallel machines using timed colored petri net.
3. To identify and analyse the deadlocks in the flexible manufacturing system that affect the production rates.
4. To validate and optimize the modelling system.

1.5 RESEARCH METHODOLOGY

This study was initiated by comprehensive study of literature in flexible manufacturing system, deadlock and petri net. It was followed by obtaining the required data of production line from Dalia Industries. These data were used to model, simulate then analyse the flexible manufacturing system with timed colored petri net. After that, analysis for the system was conducted to detect deadlock and see which deadlocked resource has impact on the system performance. Suggestions to improve the system was proposed and validation was done with help of Delmia Quest. Figure 1-1 illustrate the methodology of this work.

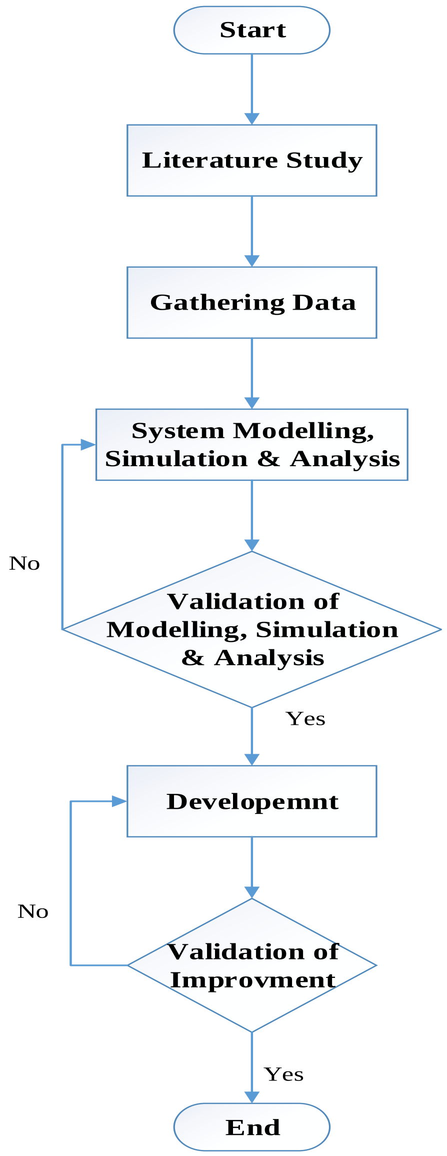

Figure 1-1: Research Methodology

1.6 SIGNIFICANCE OF THE STUDY

The results of this study provides a method to industrialists to evaluate their production systems in terms of having a deadlock, which affects manufacturing rate and flexibility in the system. This research would attract more attention for the risks of having deadlock and merits to have an improved system to achieve higher performance for greater outcomes. This will help to save time, efforts and increase profits for industries.

1.7 RESEARCH SCOPE

The scope of this research is in the range of objectives. They are as following:

1- Timed Colored Petri Net was used to model, simulate and analyse the system to check for deadlocks and make a plan to avoid them for improvement.

2- The deadlock detection and avoidance model was validated using Delmia Quest software.

3- This study focused on time and resource utilization to enhance the system without putting the required cost for deadlock detection and avoidance in consideration.

1.8 DISSERTATION OUTLINE

This research was organized as the following;

- Chapter one is an introduction of this research which includes a background of study, statement of problem, purpose and objectives of the research, research methodology, scope of this work and its importance.
- Chapter two represents the relevant literature pertaining to the current research work and discusses previous related works.
- Chapter three explains the methodology used in this work including data obtained from factory, simulation using colored petri net tool and Delmia Quest.
- Chapter four shows the simulation of the flexible manufacturing system, the results for the simulation analysis of the system for deadlock detection and avoidance, and the validation of the model by Delmia Quest.
- Chapter five summarizes the conclusion of the outcomes for this study and what was achieved. It also lists some recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses the relevant literature pertaining to the current dissertation. Section 2.2 reviews in detail flexible manufacturing system beside its advantages and disadvantages. Section 2.3 explains the deadlock problem in FMS with its types and the four solutions for it. Section 2.4 illustrates the petri net as tool to model, simulate and analyse FMS. The last section shows the previous related works to detect and avoid deadlock in FMS.

2.2 FLEXIBLE MANUFACTURING SYSTEM

2.2.1 Overview of FMS

Flexible manufacturing system is defined as a system that has number of resources able to perform different processes and joined by a transportation mechanism (Ghosh, Arapostathis, & Marcus, 1993). Park (2005) defined flexible manufacturing system as an integrated arrangement that consists of automated workstations like computer numerically controlled (CNC) machines which have ability of tool change, a storage system, hardware handling system and a computer control system that organizes the processes of the production system.

FMS was first developed in 1968 D.T.N Williamson, a worker of Molins Machine Tool company. He made the first FMS, which was called system 24 in order to produce light flat alloy components. His aim was to make a manufacturing system that can make components with large variety, load and unload tools and workpieces automatically with operating for long period at high efficiency. This FMS could not reach those