UNIVERSITI PUTRA MALAYSIA

OPTIMAL MAINTENANCE SCHEDULING FOR MULTI-COMPONENT E-MANUFACTURING SYSTEM

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OPTIMAL MAINTENANCE SCHEDULING FOR MULTI-COMPONENT E-MANUFACTURING SYSTEM

By

ALI ARAB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my beloved parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

OPTIMAL MAINTENANCE SCHEDULING FOR MULTI-COMPONENT E-MANUFACTURING SYSTEM

By

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September 2009

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Faculty : Engineering

During the recent years, development of information technology caused to develop a new industrial system which is called e-Manufacturing system. Thanks to the web-enabled manufacturing technologies, the lead times are being minimized to their extreme level, and the minimum amount of inventory is kept, though the products are being made-to order. Under these circumstances, achieving near-zero downtime of the plant floor's equipments is a crucial factor which mitigates the risk of facing unmet demands. Many researches carried out to schedule maintenance actions in short term, but none of them have utilized all of planning horizon to spread maintenance actions along available time. In this research a method of enhanced maintenance scheduling of multi-component e-Manufacturing systems has been developed. In this multi-component system, importance of all machines is considered and the benefit of the entire system in term of produced parts is taken into account (versus benefits of single machine). In proposed system, the predicted machines degradation information, online information about work in process (WIP) inventory (at inventory buffer of each work station) as well

as production line's dynamism are taken into account. All of makespans of planning horizon have been utilized to improve scheduling efficiency and operational productivity by maximizing the system throughputs. A state-of-the-art method which is called simulation optimization has been utilized to implement the proposed scheduling method. The production system is simulated by ProModel software. It plays the role of objective function of the maintenance scheduling optimization problem. Using a production related heuristic method which is called system value method, the value of each workstation is determined. These values are used to define the objective function's parameters. Then, using genetic algorithm-based software which is called SimRunner and has been embedded by ProModel, the scheduling optimization procedure is run to find optimum maintenance schedule. This process is carried out for nine generated scenarios. At the end, the results are benchmarked by two commonly used maintenance scheduling methods to magnify the importance of proposed intelligent maintenance scheduling in the multi-component e-Manufacturing systems. The results demonstrate that the proposed optimal maintenance scheduling method yields much better system value rather than sequencing methods. Furthermore, it indicates that when the mean time to repairs are longer, this method is more efficient. The results in the simulated testbed indicate that the developed scheduling method using simulation optimization functions properly and can be applied in other cases.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENJADUALAN PENYELENGGARAAN OPTIMA UNTUK KOMPONEN-BERBILANG SISTEM E-PEMBUATAN

Oleh

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Semenjak kebelakangan ini, pembangunan di dalam teknologi maklumat telah menyebabkan pembangunan satu sistem industri baru yang dipanggil sistem e-pembuatan dapat dibangunkan. Dengan munculnya teknologi pembuatan berasaskan web, masa mendulu dapat dikurangkan pada peringkat ekstrem, dan jumlah minimum inventori dapat disimpan, walaupun produk sedang di proses mengikut permintaan. Di bawah keadaan ini masa henti menghampiri kosong bagi peralatan-peralatan di kilang yang merupakan satu faktor genting dapat dicapai bagi mengurangkan risiko menghadapi permintaan yang tidak dapat dicapai. Beberapa penyelidikan telah dijalankan untuk menjadualkan tindakan-tindakan penyelenggaraan dalam tempoh singkat, tetapi tiada penyelidikan yang telah menggunakan kesemua sempadan perancangan untuk meluaskan tindakan penyelenggaraan bagi masa yang terkini. Di dalam penyelidikan ini satu kaedah penyelenggaraan berjadual telah ditingkatkan dan sistem e-pembuatan berbilang komponen telah dibangunkan. Dalam sistem berbilang

komponen, kepentingan bagi semua mesin telah diambilkira dan manfaat bagi keseluruhan sistem dalam menghasilkan satu-satu bahagian diambil kira (berbanding faedah mesin tunggal). Dalam sistem yang dicadangkan, maklumat degradasi mesin yang telah diramalkan, maklumat dalam talian mengenai kerja-kerja dalam proses (WIP) inventori (pada simpanan inventori pada setiap stesen kerja) serta kedinamikan talian pengeluaran telah diambil kira. Kesemua perancangan pembuatan pada sempadan perancangan telah digunakan untuk meningkatkan kecekapan penjadualan dan produktiviti operasi dengan memaksimumkan pengeluaran sistem. Satu kaedah terkini yang dipanggil pengoptimuman simulasi telah digunakan bagi implimentasi kaedah penjadualan dicadangkan. Sistem pengeluaran ini di simulasi menggunakan perisian ProModel. Ia memainkan peranan sebagai fungsi objektif masalah pengoptimuman bagi penyenggaraan berjadual. Menggunakan satu kaedah pengeluaran heuristik berkaitan yang dipanggil kaedah sistem nilai, nilai bagi setiap stesen kerja ditentukan. Nilai-nilai ini telah digunakan untuk menjelaskan parameter fungsi objektif. Kemudian, dengan menggunakan perisian berasaskan genetik algoritma yang dipanggil SimRunner dan telah disediakan oleh ProModel, prosedur pengoptimuman penjadualan dijalankan untuk mencari jadual penyelenggaraan yang optimum. Proses ini telah dilakukan untuk sembilan senario yang telah dijanakan. Akhirnya, keputusan-keputusan yang telah didapati dibandingkan dengan dua kaedah penjadualan penyelenggaraan yang biasanya digunakan untuk menunjukkan kepentingan kaedah penjadualan penyelenggaraan pintar yang telah dicadangkan dalam sistem e-pembuatan berbilang komponen. Keputusan yang di perolehi daripada kaedah penjadualan penyelenggaraan optima menghasilkan sistem nilai yang lebih baik berbanding kaedah bersiri. Dan juga, apabila purara masa untuk pembaikan adalah panjang. Kaedah ini adalah lebih efisien. Keputusan dalam

kaedah simulasi menunjukkan kaedah penjadualan yang di cadangkan dengan menggunakan pengoptimuman simulasi berfungsi dengan baik dan boleh di aplicasi dalam kes yang berlainan.

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I certify that a Thesis Examination Committee has met on 30 September 2009 to conduct the final examination of Ali Arab on his thesis entitled "Optimal Maintenance Scheduling for Multi-Component e-Manufacturing Systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of Universiti Pertanian Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

_____

ALI ARAB
Date: 22 December 2009

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LIST OF ABBREVIATIONS

CBM	Condition-Based Maintenance
CRM	Customer Relationship Management
D2B	Device To Business
DAQ	Data Acquisition
DEA	Data Envelopment Analysis
DOE	Design Of Experiment
DST	Decision Support Tools
ERP	Enterprise Resource Planning
FAF	Failure And Fix
FP	Fully Processed
GA	Genetic Algorithm
GEM	Generic Equipment Model
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology
IIS	Information Infrastructure System
IM	Inverse Manufacturing
IMS	Intelligent Maintenance System
IPDSS	Intelligent Predictive Decision Support System
LPT	Longest Processing Time
MES	Manufacturing Execution System

MIMOSA	Machinery Information Management Open System Alliance
MTTR	Mean Time To Repair
OHIO	Only Handle Information Once
OSA/CBM	Open System Architecture Condition Based Maintenance
PAP	Predict And Prevent
PLC	Product Life Cycle
PP	Partially Processed
RIMFDS	Real-time Intelligent Multiple Fault Diagnostic System
RNN	Recurrent Neural Network
RRBF	Recurrent Radial Basis Function
RUL	Remaining Useful Life
RV	Response Value
SCM	Supply Chain Management
SDT	Shutdown Time
SHANN	Strata Hierarchical Artificial Neural Network
SIMAP	Intelligent System for Predictive Maintenance
Sim. Opt	Simulation Optimization
SME	Small and Medium Enterprises
SOP	Standing Operator Procedure
SPT	Shortest Processing Time
TEMIC	tele-maintenance system
UML	Unified Modelling Language
VMI	Vendor Managed Inventory

WIP	Work In Process
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1.1. Introduction

In the last two decades, manufacturing industries have been transforming from mass production through flexible and lean manufacturing towards agile manufacturing and e-Manufacturing (Cheng *et al.*, 2008). For the recent years, the web-based technologies have accelerated the design and manufacturing of products. In today's competitive and challenging industrial worldwide brought by changing market conditions, social demands, regional, environmental and global regulations, it is necessary for manufacturers to speed up their response to manufacturing operations to improve productivity and resource utilization (Lee, 2003).

Utilizing the web-enabled manufacturing technologies, the lead times are being minimized to their extreme level, and the minimum amount of inventory is kept, though the products are being made-to order. Under this circumstances, achieving near-zero downtime of the plant floor's equipments is a crucial factor which mitigates the risk of facing unmet demands (Koç *et al.*, 2006).

The recent concept developed in information era to cover aforementioned needs is called "e-Manufacturing". It facilitates the plant floor to be monitored and provides an efficient information exchanges among manufacturing sub-systems and upper level enterprise. The significance of the maintenance operation is increasing because of its effects in keeping and improving uptime period and safety of the system as well as product quality. Development of the communication and information technologies has allowed the concept of e-Maintenance comes into view. In the age

of e-Business and e-Manufacturing, e-Maintenance provides the opportunity for evolution of a new maintenance generation which using predictive information of future condition of equipments tries to eliminate any unplanned downtime of the system (Muller *et al*., 2008).

In traditional point of views, it often seems that machines fail suddenly, but in reality, equipments, especially mechanical systems are degraded before they fail. The degradation process is invisible but thanks to development of diagnostic and prognostic technologies it can be measured (Lee *et al.*, 2006b). Watchdog Agent™ is one of the tools developed in centre for Intelligent Maintenance System (IMS). Its approach is a modification of condition-based maintenance strategy relying on prediction, rather than only equipment's current condition (Djurdjanovic *et al.*, 2003). Developing this approach ultimately caused to replacing the traditional fail and fix (FAF) practice to predict and prevent (PAP) methodology. In this research, the degradation conditions of equipments have been taken into account at the beginning of each shift to nominate machines to be repaired during the shift to prevent any possible failure before occurrence.

Predicting the future condition of equipments for achieving near-zero breakdown which is referred to e-Maintenance is one of the most critical aspects of e-Manufacturing concept. For mitigating disastrous impacts of unplanned downtime in industries, some infotronic-based prognostic and diagnostic tools have been developed to assess and predict the equipment performance degradation. A lot of sophisticated embedded systems and sensors in a computerized platform are capable to deliver data about equipment's condition and performance. But the problem is that a little practical use is made of majority of these data (Lee *et al.*, 2006a). Such invaluable information about equipment's status in future should be utilized by