



Faculty of Manufacturing Engineering

**NEW HYBRID QUICK RESPONSE MANUFACTURING FRAMEWORK TO
IMPROVE DELIVERY PERFORMANCE AT ENGINEER-TO-ORDER COMPANY**

Bong Cheng Siong

Doctor of Engineering

2019

**NEW HYBRID QUICK RESPONSE MANUFACTURING FRAMEWORK TO
IMPROVE DELIVERY PERFORMANCE AT ENGINEER-TO-ORDER COMPANY**

BONG CHENG SIONG

**A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Engineering**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Engineering.

Signature :.....

Supervisor Name :.....

Date :.....

DECLARATION

I declare that this thesis entitled “New Hybrid Quick Response Manufacturing Framework To Improve Delivery Performance At Engineer-To-Order Company” 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 :

Date :

DEDICATION

To my beloved family, supervisor and friends for always supporting me along the way
to accomplish my doctorate thesis.

ABSTRACT

The competitiveness and growth of the small and medium enterprises (SMEs) is critical for the Malaysian economy. In the last few years amidst the volatile external environment and escalating global competition, SMEs have witnessed a marked improvement in their performance. Malaysian SMEs are expected to contribute 42% to the country's gross domestic product (GDP) by 2020, remain as an important economic agent to transition the economy to a developed nation in the years to come. As such, productivity of SMEs is imperative to ensure the competitiveness of manufacturing organization in the country. The present scenario reveals that most SMEs supply custom engineered products are confronted with various challenges in retaining their competitive advantages in the global market. Hence, selecting the best practices that associated to their competitive priorities will help the company outperforms their competitors in the long term. However, many failed to do so due to their rush to emulate the success of their counterparts. This research study has set out for an engineer-to-order (ETO) manufacturing company that experiences poor on-time delivery (OTD) performance of about 54%. The aim of the study was to reduce the lead time and hence improve OTD to customers by designing a new hybrid Quick Response Manufacturing (QRM) framework in the organization. The objectives and methodologies include designing a QRM based material flow system controlled by capacity utilization to ease the overloading in the production. A simulation base model was built and validated followed by experimentations of capacity utilization based control (UBC) system. The deciding factors such as throughput (TP), work-in-process (WIP) and average manufacturing critical-path time (MCT) per job were analysed and compared. To address the limitations of QRM, the second phase is designing a system integrated with Lean and TQM practices to eliminate office wastes and to cultivate concept of self-assessment respectively. This hybrid QRM was also meant to create a balance and sustainability in the long run. The last phase is engaging a case company to validate the developed hybrid system in the real-life environment. Simulation results showed that UBC system performed better than the current cost based production in the case company. The achievement of the objectives predetermined above include WIP and MCT reduced by 30% and 18% respectively, resulting improvement of OTD from 54% to 75%. This has led to the economic impacts particularly with respect to TP and sales increased by 31% and 69% respectively after the deployment of the new system in the case company. The thesis identifies issues arising from the application of hybrid QRM in the job shops which have implications for industry practices. It concludes by outlining further research that can be undertaken in the emerging trend of Industry 4.0.

ABSTRAK

Daya saing dan pertumbuhan perusahaan kecil dan sederhana (PKS) adalah kritikal bagi ekonomi Malaysia. Dalam beberapa tahun yang lepas di mana persekitaran luaran yang tidak menentu dan persaingan global yang semakin meningkat, PKS telah menyaksikan peningkatan yang ketara dalam prestasi mereka. PKS Malaysia dijangka menyumbang 42% kepada Keluaran Dalam Negara Kasar (KDNK) menjelang 2020, kekal sebagai ejen ekonomi yang penting untuk mengembangkan ekonomi ke negara maju pada tahun yang akan datang. Oleh itu, produktiviti PKS adalah penting untuk memastikan daya saing organisasi pembuatan di negara ini. Senario sekarang mendedahkan bahawa kebanyakan PKS yang membekalkan produk kejuruteraan tersuai berhadapan dengan pelbagai cabaran untuk mengekalkan kelebihan daya saing mereka di pasaran global. Oleh itu, memilih praktik terbaik yang berkaitan dengan keutamaan kompetitif akan membantu syarikat mengalahkan pesaing mereka dalam jangka panjang. Walau bagaimanapun, banyak yang gagal melakukannya kerana tergesa-gesa untuk mencontohi kejayaan rakan sejawat mereka. Kajian penyelidikan ini telah dimulakan untuk syarikat pembuatan ETO (Engineer-To-Order) yang mengalami prestasi penghantaran tepat pada masa (On Time Delivery, OTD) yang teruk iaitu 54% sahaja. Tujuan kajian ini adalah untuk mengurangkan masa pembuatan, oleh itu memperbaiki OTD kepada pelanggan dengan merekabentuk rangka kerja Pembuatan Respons Pantas (Quick Response Manufacturing, QRM) hibrid baru. Objektif dan metodologi termasuk merekabentuk sistem aliran bahan QRM yang dikawal oleh pemuatan kapasiti untuk mengurangkan beban dalam produksi. Model asas simulasi dibina dan disahkan diikuti dengan eksperimen sistem kawalan berdasarkan pemuatan kapasiti (Utilization Based Control, UBC). Faktor-faktor penentu seperti penghantaran (Throughput, TP), kerja dalam proses (Work In Process, WIP) dan masa kritikal pembuatan (Manufacturing Critical-path Time, MCT) akan dianalisis dan dibandingkan. Untuk menangani batasan QRM, fasa kedua adalah merekabentuk sistem yang diintegrasikan dengan praktik kejut (Lean) dan pengurusan kualiti menyeluruh (Total Quality Management) untuk menyingkirkan pembaziran dan memupuk konsep penilaian diri. QRM hibrid ini juga bertujuan untuk mewujudkan keseimbangan dan kemampuan dalam jangka panjang. Fasa terakhir adalah melibatkan syarikat kes untuk mengesahkan sistem hibrid baru di dalam persekitaran sebenar. Hasil simulasi menunjukkan bahawa sistem UBC adalah lebih baik daripada produksi berasaskan kos dalam syarikat kes. Pencapaian objektif yang ditentukan awal termasuk WIP dan MCT telah dikurangkan sebanyak 30% dan 18% masing-masing, turut menambahbaikkan OTD dari 54% ke 75%. Ini telah membawa kepada kesan ekonomi terutamanya berkaitan penghantaran (TP) dan jualan yang meningkat sebanyak 31% dan 69% masing-masing selepas penggunaan sistem baru dalam syarikat kes. Tesis ini telah mengenalpasti isu-isu yang timbul semasa penggunaan QRM hibrid di tempat kerja yang mempunyai implikasi untuk praktik industri. Secara kesimpulan, ia juga menggariskan penyelidikan lebih lanjut yang boleh dilaksanakan dalam tren baru Industri 4.0.

ACKNOWLEDGEMENTS

I wish to express my sincere and deepest gratitude to all people who helped me to the successful completion of my DEng degree at Universiti Teknikal Malaysia Melaka. I am truly grateful to Prof. Dr. Chong Kuan Eng, my main supervisor, for his unconditional support and his invaluable advice to guide me through this exhilarating journey from nothing to this piece of binding. I would like to express my grateful thanks to MOHE and UTeM for the research funding to make this study possible.

I also wish to express my sincere appreciation to the company that I'm attached to. This study would not be successful without the support and cooperation given by its management.

Last but not least, I wish to acknowledge the unconditional love and encouragement from my family and friends during the hard times and long erratic working hours, especially my wife, Kenix and my three lovely kids, Yu Yang, Yu Hsien and Yu Jay.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	x
LIST OF APPENDICES	xv
LIST OF ABBREVIATIONS	xvi
LIST OF SYMBOLS	xx
LIST OF PUBLICATIONS	xxi
CHAPTER	
1. INTRODUCTION	1
1.1 Background to the research	1
1.2 Research problem	2
1.3 Research objectives	4
1.4 Research scope	5
1.5 Significance of the study	7
1.6 Structure of the thesis	8
2. LITERATURE REVIEW	11
2.1 Introduction	11
2.2 Small and medium enterprises within Malaysian economy	14
2.2.1 Challenges to Malaysian's SMEs	19
2.3 Customized manufacturing	21
2.3.1 Customization	21
2.3.2 Production systems in ETO companies	23
2.3.3 Competitive priorities	25
2.3.4 Dragging problems in ETO companies	27
2.3.4.1 Causes to the problems	30
2.4 Manufacturing paradigm	30
2.4.1 The rise of time-based competition paradigm	32
2.4.2 From time-based paradigm to implementing responsive manufacturing	34
2.4.3 Responsiveness as competitive advantage in ETO companies	35
2.4.4 Moving away from cost-based competition	36
2.4.5 Lead time as a strategic metric	37
2.4.6 Comparison of manufacturing paradigms	38

2.5	Quick response manufacturing	42
2.5.1	The QRM core concepts	44
2.5.2	The QRM principles	47
2.5.2.1	QRM based material flow	48
2.5.2.2	Variability	51
2.5.2.3	Little's law	53
2.5.2.4	Queuing theory	54
2.5.2.5	From push to pull manufacturing	55
2.5.2.6	On-time delivery - the response time spiral	56
2.5.2.7	Material requirements planning	57
2.5.2.8	Alignment between finance and operations	60
2.5.3	Paired-cell overlapping loops of cards with authorization (POLCA)	61
2.5.4	Manufacturing critical-path time (MCT)	64
2.5.5	Performance measures	67
2.5.6	QRM practices and approaches	69
2.5.7	Potential for integrating other approaches	73
2.5.7.1	Evaluation of integrable approaches	77
2.6	Summary	81
3.	METHODOLOGY	83
3.1	Introduction	83
3.2	Research design	83
3.3	Preliminary study	85
3.3.1	Background of the case company	85
3.3.2	Overview of order fulfilment process	87
3.4	Data collection and analysis	89
3.4.1	Historical data	90
3.4.2	Delivery process of bonding insert	90
3.4.3	What is bonding insert	91
3.4.4	MCT mapping	93
3.4.5	Causes of long waiting time	99
3.4.6	Operating curve	100
3.5	QRM based material flow design	102
3.5.1	Utilization based control (UBC)	103
3.5.2	Simulation	104
3.5.2.1	Model scope and level of details	105
3.5.2.2	Assumption	106
3.5.2.3	Model translation	107
3.5.2.4	Verification and validation	109
3.5.3	Experimental design	111
3.5.3.1	Experimental simulation flow	112
3.6	New hybrid QRM framework	114
3.6.1	School of thoughts: manufactuirng vs management	117
3.6.2	Concepts of design	118
3.6.2.1	Company-wide application	120
3.6.2.2	QRM: organization structure (TQM: Driver)	122
3.6.2.3	QRM: system dynamics (TQM: System)	124

3.6.2.4	QRM: the power of time (TQM: Result)	128
3.6.3	Self assessment	130
3.7	Hybrid QRM framework validation	130
3.7.1	Current operation of the case company	132
3.7.2	Data administration via MRP system	133
3.8	Summary	135
4.	RESULT AND DISCUSSION	136
4.1	Simulation experimental results	136
4.1.1	Discussion of simulation results	140
4.2	Implementation of hybrid QRM framework	142
4.2.1	MPSB plantwide application	143
4.2.2	MPSB organization structure and driver	145
4.2.3	MPSB system deployment	148
4.2.4	MPSB performance indicators	164
4.2.5	Discussion of framework implementation	166
4.3	Key performances for framework validation	168
4.3.1	On time delivery	168
4.3.2	MCT touch time	170
4.3.3	Lead time	171
4.3.4	Customer satisfaction	173
4.3.5	Discussion of manufacturing key performances	174
4.4	Merit of combined strategies in the framework	179
4.4.1	QRM and Lean: all-round time compressor for MPSB	179
4.4.2	QRM and TQM: a winning combination for MPSB	182
4.4.3	Hybrid QRM thrives for balance and sustainability	185
4.5	Research contributions	187
4.6	Economic impact analysis	191
4.6.1	Work-in-process	191
4.6.2	Throughputs, sales and productivity	192
4.7	Summary	195
5.	CONCLUSION AND RECOMMENDATIONS	198
5.1	Summary of research motivation and conclusions	198
5.2	Research limitations	202
5.3	Recommendations for future research	202
	REFERENCES	204
	APPENDICES	239

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Definition of SMEs in Malaysia (SME Corp, 2018)	14
2.2	Profiles of SMEs	15
2.3	SME GDP by economic sector (constant 2010 prices) (SME Corp, 2018)	17
2.4	SME GDP and overall GDP share by key economic sector (constant 2010 prices) (SME Corp, 2018)	18
2.5	Most representative studies of competitive priorities (modified from Bouranta and Psomas 2017)	26
2.6	Levels of customization (modified from Lampel and Mintzberg, 1996)	29
2.7	Definitions of manufacturing paradigm in the literatures	32
2.8	George Stalk's TBC related publications (Emboava et al., 2017)	33
2.9	Strategic paradigm for manufacturing management and their drivers (Fernandes and Filho, 2009)	39
2.10	Taxonomic comparison of manufacturing paradigms (Nambiar, 2010)	39
2.11	A comparison between TQM and QRM	42
2.12	Rajan Suri's QRM related publications	43

2.13	Differences between POLCA and Kanban (Krishnamurthy and Suri, 2009)	63
2.14	Impact of lead time reduction on on-time performance (Ericksen and Suri, 2001)	68
2.15	Summary of performance measures in the case company	68
2.16	QRM principles, tools or models/frameworks used in the papers reviewed	70
2.17	Brief description of some integrated manufacturing	74
2.18	Summarized decision from the evaluation of integrable approaches	81
3.1	Project team members	90
3.2	Fabrication parts and vendor parts for BI	92
3.3	Production steps and processing time of fabrication parts	94
3.4	The scope of the model (How, 2016)	106
3.5	Model level of detail (How, 2016)	106
3.6	Average MCT per job result from the simulation base model	109
3.7	Validation steps for average MCT per job (How, 2016)	110
3.8	TQM self-assessment questionnaire customization	130
3.9	Different model of machine used in each process and shift pattern	132
3.10	Working and break hours for office, day and night shift staffs	133
4.1	Result of 10 replications current system	137
4.2	Result of 10 replications at 90% UBC system	137
4.3	Result of 10 replications at 85% UBC system	138
4.4	Result of 10 replications at 80% UBC system	138
4.5	Results of the current system and simulated UBC system	140

4.6	Lead time reduction strategies	149
4.7	Company scorecard	165
4.8	Departmental scorecard	165
4.9	Example of OTD performance tracking for MPSB and its subcontractors	169
4.10	Summary of pre- and post-QRM implementation performances	175
4.11	Wastes identified in office operations	180
4.12	Improvement gain from Lean applications	181
4.13	Summary of economic impacts	195

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	OTD from 2013 to 2016 at the case company (engineer-to-order SME)	3
1.2	Overview of manufacturing process	6
1.3	An overview of the thesis outline with K-Chart	10
2.1	Literature review conducted for this research	13
2.2	SME GDP and overall GDP growth (%) (SME Corp, 2018)	15
2.3	Share of SME exports by economic sector (%) (SME Corp, 2018)	16
2.4	Percentage share of SMEs in the manufacturing sector by sub-sector (%) (SME Corp, 2017)	16
2.5	Employment share of SMEs to total employment (%) (SME Corp, 2018)	17
2.6	Typical flow of goods in ETO production (Bertrand et al., 1993)	23
2.7	Prevailing operations strategy model (Boyer and Lewis, 2002)	26
2.8	The manufacturing paradigm (Jovane et al., 2003)	31
2.9	Manufacturing paradigm model (Koren, 2010)	31
2.10	Midwest manufacturing company's order of progression (Suri, 2010a)	37
2.11	The key production characteristics of continuum	40

2.12	Malaysia business excellence framework (MBEF, 2016)	41
2.13	Cost-based thinking vs. QRM system dynamics theory (Suri, 2010a)	46
2.14	QRM principles supercede traditional beliefs (adapted from Suri, 1998)	48
2.15	A simulation – industrial study for material flow control mechanism	50
2.16	QRM takes Lean to the next level	52
2.17	Operating curve – impact of utilization and variability on CT (Poiger, 2010)	55
2.18	Push vs pull system production strategy (Hopp and Spearman, 2011)	56
2.19	Response time spiral (Joing, 2004)	57
2.20	Overview of MRP (adapted from Imetieg and Lutovac, 2015)	59
2.21	Three key financial metrics in a manufacturing company (Goldratt and Cox, 2014)	61
2.22	POLCA cards (Suri, 1998)	62
2.23	Mechanism flow of POLCA cards (Suri, 1998)	62
2.24	Example of an MCT map (Suri, 2014)	67
3.1	Chapter structure and overall process flow of the study	84
3.2	An ETO company selected for this study	85
3.3	Functional job-shop layout of MPSB	87
3.4	Generic flow of goods at MPSB (derived from New, 1977)	87
3.5	ETO production flow at MPSB & research area	88

3.6	Die bonding machine	91
3.7	Die bonding process (PECO, 2016)	92
3.8	Rejection rate since 2014	93
3.9	Proess mapping of BI	94
3.10	Job order form (JOF)	95
3.11	MCT mapping of BI	98
3.12	Ratio between touch times and waiting times	98
3.13	Lead time of BI	99
3.14	Why-why analysis	100
3.15	Operating curve of BI (representing current production system)	102
3.16	Conceptual QRM based material flow system	103
3.17	Simulation conceptual modelling (How, 2016)	104
3.18	The process flow of the simulation modelling	105
3.19	Activity flow of base model	108
3.20	Base model in WITNESS simulation	108
3.21	Normality test for average MCT per job	110
3.22	One-sample t test of average MCT per job	110
3.23	Power and sample size test for average MCT per job	110
3.24	Flow chart of experimental simulation model	113
3.25	Utilization based control material flow illustration	114
3.26	Hybrid QRM framework development process	116
3.27	QRM integrated with Lean	118
3.28	New hybrid QRM framework	119
3.29	Inclusive view of QRM core concept – companywide application	121

3.30	Inclusive view of QRM core concept – organization structure	123
3.31	Inclusive view of QRM core concept – system dynamics	125
3.32	Inclusive view of QRM core concept – the power of time	129
3.33	Precision parts produced by MPSB	131
3.34	Data from MRP system	134
4.1	Throughput result of current and UBC systems	138
4.2	WIP result of current and UBC systems	139
4.3	Average MCT per job of current and UBC systems	139
4.4	Average MCT per job for different mechanisms	141
4.5	Hybrid QRM system realization	143
4.6	Hybrid QRM program implementation milestone	144
4.7	Core values of “FASTTEAM” at MPSB	145
4.8	QRM program related tagline	146
4.9	Headline goals at MPSB	146
4.10	LT improvement analysis through reducing V and U	149
4.11	Lean application in office operations	151
4.12	Time plan of installing MRP system - MAPS	152
4.13	Office network layout and MAPS usage	152
4.14	Manufacturing network layout and MAPS usage	153
4.15	Barcode system for job scanning and tracking	154
4.16	Data entry interface for new job	155
4.17	Example of machine utilization report	156
4.18	Jobs flow control before and after QRM implementation at MPSB	157
4.19	Sample of QBR report from customer – business criteria	158

4.20	Sample of QBR report from customer – quality criteria	159
4.21	Quality policy of the company	160
4.22	Quality objectives of the company	161
4.23	One point lesson (OPL)	162
4.24	Trainings conducted for internal staffs	163
4.25	Overall OTD trend for key customers after hybrid QRM implementation	170
4.26	MCT comparison for BI product before and after QRM implementation	171
4.27	LT monitoring for product BI after hybrid QRM implementation	173
4.28	Customer satisfacton index	174
4.29	Engineering change request in the delivery process	177
4.30	General info on early/on time/late delivery	178
4.31	Lean application in office operations	181
4.32	Team assessment using MBEF criteria	184
4.33	Applicable areas from other approaches in QRM	184
4.34	Balance viewpoint of combined QRM, Lean and TQM	186
4.35	Sustainability viewpoint of TQL (TQM+QRM+Lean)	187
4.36	Average work-in-process (WIP) inventory	192
4.37	Comparison of TP before and after hybrid QRM implementation	193
4.38	Comparison of sales before and after hybrid QRM implementation	194

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Excellence Models/National Quality Awards	239
B	Ten QRM Principles	244
C	List of Components in Simulation Base Model	245
D1	Input Data of Arrival Time	248
D2	Input Data of Process Route	253
D3	Input Data of Process Time	257
E	Verification of Simulation Model	261
F	MBEF Guiding Principles	262
G	MBEF Assesment Criteria	266
H	Job Order Form Design and Source Code	272
I	Machine Utilization Report Design and Source Code	276
J	Various Departments Involve in Project Activities	290
K	TQM Self-Assessment Questionnaire	291
L	OTD Performance Breakdown by Key Customers	293
M	MPSB Customer Survey Form	294
N	AS 9100 QMS Standard fro Aerospace	295

LIST OF ABBREVIATIONS

AFI	-	Areas for Improvement
AM	-	Agile Manufacturing
ASB	-	Assembly
ATO	-	Assemble-to-Order
BI	-	Bonding Insert
BTO	-	Buy-to-Order
CM	-	CNC Milling
CNC5	-	CNC 5axis
CNCG	-	CNC Grinding
CP	-	Competitive Priorities
CODP	-	Customer-order-decoupling-point
CT	-	Cycle Time
CV	-	Coeficient of Variation
EFQM	-	European Foundation for Quality Management
EM	-	Excellence Model
ERP	-	Enterprise Resource Planning
ETO	-	Engineer-to-Order
EDM	-	Electrostatic Discharge Machine
GDP	-	Gross Domestic Product

GF1	-	Manual Grinding
GF2	-	Surface Grinding
HMS	-	Holonic Manufacturing System
IoT	-	Internet of Things
JIT	-	Just-in-Time
JG	-	Jig Grinding
JOF	-	Job Order Form
LM	-	Lean Manufacturing
LSS	-	Lean Six Sigma
LT	-	Lead Time
MAPS	-	Manufacturing Planning System
MBEF	-	Malaysia Business Excellence Framework
MBNQA	-	Malcolm Baldrige National Quality Award
MES	-	Manufacturing Execution System
MC	-	Mass Customization
MCT	-	Manufacturing Critical-Path Time
MI	-	Milling
MPC	-	Malaysia Productivity Corporation
MRP	-	Material Requirements Planning
MTO	-	Make-to-Order
MTS	-	Make-to-Stock
NCL	-	CNC turning
NQA	-	National Quality Award
OC	-	Operating Curve

OPL	-	One Point Lesson
OPP	-	Order-penetration-point
OTD	-	On-time delivery
OTR	-	Order to Receipt
PG	-	Profile Grinding
PMIEA	-	Prime Minister Industry Excellence Award
POLCA	-	Paired Cell Overlapping Loops of Cards with Authorization
PT	-	Process Time
QBR	-	Quarterly Business Report
QC	-	Quality Control
QRM	-	Quick Response Manufacturing
QT	-	Queuing Time
RFID	-	Radio Frequency Identification
SCV	-	Squared Coefficient of Variation
SD	-	Super Drilling
STS	-	Ship-to-Stock
SME	-	Small and medium enterprises
T	-	Raw Process Time
TBC	-	Time-based Competition
TBM	-	Time-based Manufacturing
TOC	-	Theory of Constraint
TL	-	Turning
TP	-	Throughput
TQL	-	TQM-QRM-Lean

TPS	-	Toyota Production System
TQM	-	Total Quality Management
U	-	Utilization Factor
UBC	-	Utilization Based Control
UP	-	Up Time
V	-	Variability Factor
WC	-	Wire Cutting
WIP	-	Work-in-process