



**Faculty of Manufacturing Engineering**

**HUMAN SYSTEM MODELLING FOR LABOUR  
UTILISATION AND MAN-MACHINE CONFIGURATION AT  
CELLULAR MANUFACTURING**

**Rohana binti Abdullah**

**Doctor of Philosophy**

**2017**

**HUMAN SYSTEM MODELLING FOR LABOUR UTILISATION AND  
MAN-MACHINE CONFIGURATION AT CELLULAR MANUFACTURING**

**ROHANA BINTI ABDULLAH**

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

**Faculty of Manufacturing Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2017**

## DECLARATION

I declare that this thesis entitled “Human System Modelling for Labour Utilisation and Man-Machine Configuration at Cellular Manufacturing” 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 : .....

## 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 Philosophy.

Signature : .....

Supervisor's Name : .....

Date : .....

Signature : .....

Co-Supervisor's Name : .....

Date : .....

## **DEDICATION**

To my beloved parents, husband and children.

## ABSTRACT

Manufacturing complexity has become more challenging with increased in demand fluctuation, product customisation and shorter lead time expectation. It is becoming more crucial to measure manufacturing complexity to better recognise and control the various manufacturing components to achieve optimum manufacturing performance. Cellular manufacturing or group technology is a method used to manage manufacturing complexity based on clustering of different types of equipment to process parts. The organisational structure of cellular manufacturing will always need to be flexible for reconfiguration to address rapid changes in customer requirement especially in managing its dual constraints; human and machine. Very often, the human component is overlooked or overestimated due to poor understanding of the effects of human constraints and lack of study is linked to the difficulty to model human's behaviour. The purpose of this study is to develop a human system model to fill the gap in the study of human constraints on cellular manufacturing's performance. As such, a new human system framework focusing on the aspects of human dynamics and attributes was designed to be integrated with the predetermined time standards system in an expert system, eMOST. The new human system model was evaluated for applicability at the actual manufacturing environment through five case studies where accurate labour utilisation and man-machine configuration information were conceived. Thus, the newly defined approach was able to efficiently improve data capture, analysis and model human constraints. The human information from the model was integrated with other manufacturing resources using WITNESS simulation modelling tool focusing on the bottleneck area to further evaluate the dynamic impact of these components on the manufacturing performance. Simulation modelling experiments use has also proven advantageous to change manufacturing configurations and run alternative scenarios to improve the efficiency of the system in terms of the throughput, cycle time, operator utilisation and man-machine configuration. The findings of this study enabled the management to make good decisions to efficiently manage the human resource and better predictions to reconfigure and competently manage resources allocation.

## ABSTRAK

*Industri pembuatan menjadi lebih mencabar dengan peningkatan dalam ketidaktentuan permintaan pelanggan, kepelbagaian produk dan jangkaan masa pengeluaran yang lebih pendek. Kepentingan untuk mengukur kerumitan pembuatan bertambah penting bagi lebih mengenali dan mengawal pelbagai komponen pembuatan untuk mencapai prestasi pembuatan optimum. Pembuatan selular atau teknologi kumpulan adalah satu kaedah yang digunakan untuk menguruskan kerumitan pembuatan berdasarkan pengelompokan jenis peralatan untuk memproses produk. Struktur organisasi pembuatan selular perlu sentiasa menjadi lebih fleksibel untuk dikonfigurasi semula bagi menangani perubahan pesat dalam keperluan pelanggan terutama dalam menguruskan kekangan dual; manusia dan mesin. Komponen manusia sering diabaikan atau dipandang remeh kerana kurang pemahaman mengenai kesan kekangan manusia dan kekurangan kajian dikaitkan dengan kesukaran untuk model tingkah laku manusia. Tujuan kajian ini adalah untuk membangunkan satu model sistem manusia untuk mengisi jurang dalam kajian kekangan manusia kepada prestasi pembuatan selular. Oleh itu, satu rangka kerja sistem manusia baru memberi tumpuan kepada aspek dinamik dan sifat-sifat manusia telah direka untuk disepadukan dengan sistem standard masa yang telah ditetapkan menggunakan sistem pakar, eMOST. Model sistem manusia baru ini telah dinilai kesesuaiannya di persekitaran pembuatan yang sebenar melalui lima kajian kes bagi menghasilkan maklumat mengenai penggunaan buruh dan konfigurasi manusia-mesin yang tepat. Oleh itu, pendekatan yang baru ditakrifkan ini dapat membantu dalam pengumpulan data, analisis dan kekangan manusia dengan cekap. Maklumat daripada model bersepadu ini berserta dengan data sumber pembuatan lain dapat digabungkan di dalam pemodelan simulasi WITNESS untuk menilai lebih lanjut kesan dinamik komponen manusia, mesin dan bahan ini terhadap prestasi pembuatan. Penggunaan kaedah model eksperimen simulasi juga sangat efektif bagi menukar konfigurasi pembuatan dan menjalankan senario alternatif untuk meningkatkan kecekapan sistem terutama dari aspek jumlah pengeluaran, masa, penggunaan manusia serta konfigurasi manusia dan mesin. Hasil kajian ini membolehkan pihak pengurusan membuat perancangan yang lebih berkesan dalam pengurusan sumber manusia dan membuat jangkaan lebih tepat dalam merangka konfigurasi sumber-sumber pembuatan dengan lebih kompeten.*

## ACKNOWLEDGEMENTS

My profound gratitude goes to Almighty Allah (SWT), the Great and the Most Beneficent, all praise and glory are to Him alone for endowing me the wisdom, knowledge, health, time, resources and opportunity to see this dream a reality. Special thank goes to my supervisor, Assoc. Prof. Dr Md Nizam Abdul Rahman for his valuable guidance, constructive comments and careful reading to shape this thesis into its final form. Sincere appreciation also goes to my co-supervisors, Assoc. Prof. Dr Rizal Salleh and Allahyarham Assoc. Prof. Dr Mohamed Khaled Omar for their advice and assistance. To the Ministry of Higher Education Malaysia and Universiti Teknikal Malaysia Melaka, thank you for the sponsorship opportunity. I am also indebted to my beloved colleagues and friends for their words of wisdom and encouragement during my lowest point in life when I lost my youngest child during this study. I would have long given up this dream if it weren't for all of you behind me cheering and lifting my spirit up. My heartfelt thanks to my ex-Industrial Engineers at ON Semiconductor, Jezzery and Sukri for the great teamwork we had especially on the manpower utilisation project that had merit us to win the Engineering Award. Our success was the motivation for this study. To my beloved family, I wouldn't persevere and be this strong without you as my inspiration; husband Mohamad Rosli Sukiman and children, Nur Athirah, Nur Addini and Adi Muzaffar. To Adik, Allahyarhamah Nur Ayuni, keep sending your prayers from Heaven. Deepest gratitude to my parents and siblings, I love all of you so much!

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF APPENDICES</b>	<b>xii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xiii</b>
<b>LIST OF PUBLICATIONS</b>	<b>xv</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem statement	3
1.3 Research objectives	5
1.4 Research significance	6
1.5 Scope of research	7
1.6 Limitations of research	9
1.7 Research outline	10
1.8 Structure of thesis	12
<b>2. LITERATURE REVIEW</b>	<b>15</b>
2.1 Manufacturing performance and productivity	17
2.2 Labour productivity	19
2.3 Productivity loss and lean concept	20
2.4 The need to develop human system models	23
2.5 Review of human system theories, models and frameworks	25
2.6 Constraint viewpoints in human systems modelling	37
2.7 Human dynamics and attribute	41
2.8 Integrated use of static and dynamic system modelling technique	42
2.9 CIMOSA integrated human system framework	44
2.10 The need for expert system in productivity management	46
2.11 Work study in support of human systems modelling	48
2.11.1 M2M work study technique	54
2.12 Dynamic modelling using simulation	55
2.13 Summary of literature review	60
2.14 Difference between previous research works and this study	62
<b>3. RESEARCH METHODOLOGY</b>	<b>65</b>
3.1 Types of research method used	65
3.1.1 Exploratory	65
3.1.2 Descriptive	66
3.1.3 Explanatory	66

3.1.4	Case study implementation	67
3.1.5	Research phases and methods	68
3.2	General research methodology flow	69
3.3	Phase one: conceptual human systems framework	70
3.3.1	M2M mathematical model	71
3.3.2	M2M Microsoft Excel spreadsheet template	73
3.3.3	Maynard operational sequence technique (MOST)	78
3.4	Phase two: development of HSM expert system	80
3.4.1	Expert system requirement gathering	82
3.4.2	eMOST expert system architecture	82
3.5	Phase three: enterprise HSM model evaluation	83
3.6	Phase four: dynamic resource modelling using simulation	85
3.6.1	Problem formulation	88
3.6.2	Setting objective and overall project plan	88
3.6.3	Model conceptualization	88
3.6.4	Verification and validation	90
3.6.5	Simulation based experiment	90
3.7	Summary of research methodology	93
<b>4.</b>	<b>RESULTS</b>	<b>95</b>
4.1	Phase one: conceptual human systems model framework	96
4.2	Phase two: eMOST expert system development	99
4.2.1	Planning and analysis	100
4.2.2	Design and prototyping	107
4.2.3	System development	109
4.3	Phase three: HSM evaluation at actual production system	114
4.3.1	Case study one: wafer saw operation	119
4.3.2	Case study two: die-bond operation	124
4.3.3	Case study three: wire-bond operation	129
4.3.4	Case study four: mold operation	134
4.3.5	Case study five: final test operation	139
4.4	Phase four: dynamic resource modelling using simulation	143
4.4.1	Problem formulation	144
4.4.2	Objective setting	145
4.4.3	Model conceptualization	146
4.4.4	Data collection	147
4.4.5	Model verification and validation	149
4.4.6	Simulation based experiment	152
4.5	Summary of results	157
<b>5.</b>	<b>DISCUSSION</b>	<b>160</b>
5.1	Human system conceptual model and enterprise system	161
5.2	Case studies to evaluate the static enterprise model	164
5.3	Simulation modelling and manufacturing performance	169
5.4	Contribution to knowledge	171
<b>6.</b>	<b>CONCLUSION AND FUTURE WORKS</b>	<b>174</b>
6.1	Research summary	175
6.2	Research achievements	176

6.3	Critical review of research	179
6.4	Future works	180
<b>REFERENCES</b>		<b>183</b>
<b>APPENDICES</b>		<b>209</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Human system modelling phases	11
2.1	Mathematical approach in human modelling	29
2.2	Theoretical frameworks on human factors and modelling	33
2.3	HSM categorised by human issues	40
2.4	Human competency level definition	42
2.5	Computerized PTS system	53
2.6	Difference between discrete and continuous models	56
2.7	Features comparison of simulation software	59
3.1	Research approach	68
3.2	M2M template description	77
3.3	Man to machine (M2M) analysis example	80
3.4	Simulation experiment input parameter boundaries	93
4.1	Expert system functional requirement	103
4.2	Software requirement for eMOST expert system	104
4.3	Hardware requirement for expert system development	106
4.4	Network requirement for expert system	107
4.5	Sequence diagram design of eMOST expert system	108
4.6	eMOST expert system design summary	111

4.7	Description of the SO8 manufacturing process	117
4.8	M2M wafer saw Microsoft Excel value	123
4.9	M2M die-bond Microsoft Excel value	128
4.10	M2M wire-bond Microsoft Excel value	132
4.11	Summary of die-bond process information	148
4.12	Operator activity summary information	149
4.13	Actual and simulation output comparison	152
4.14	Simulation experiment input parameter boundaries	153
4.15	Information on the different models used in the experiment	154
4.16	Results of experiment one	155
4.17	Results of experiment two	156
4.18	Results of experiment three	156
5.1	Summary of case study results	165
6.1	Summary of research achievements	177

## LIST OF FIGURES

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Global labour productivity level	20
2.2	The 16 kinds of loss	22
2.3	Approach in developing human system model	25
2.4	Dynamic theory of personality	27
2.5	General framework for modelling human performance	32
2.6	Different types of human system viewpoints	38
2.7	CIMOSA integrated human system model	45
2.8	Productivity management process	46
2.9	Simulation modelling general steps	57
3.1	Four-step case study implementation approach	67
3.2	Four-phase approach to research implementation	70
3.3	The M2M utilisation concept	73
3.4	M2M Microsoft Excel template	76
3.5	System development life cycle (SDLC)	81
3.6	Initial expert system architecture design	83
3.7	Simulation process steps	87
3.8	Simulation based experiment process flow	92
4.1	Enterprise HSM conceptual framework	96

4.2	Integrated static and dynamic human system model	99
4.3	M2M Microsoft Excel design and analysis features	101
4.4	User requirement activity diagram	102
4.5	The three-tier architecture model	107
4.6	Navigation design of expert system	110
4.7	SO8 manufacturing process flow	116
4.8	Existing SO8 equipment layout and operator allocation	118
4.9	Representation of wafer and die	119
4.10	Summary result of wafer saw operator activity	121
4.11	eMOST wafer saw operator M2M values	122
4.12	Wafer saw operator utilisation	124
4.13	Example of a lead frame	125
4.14	Summary of die-bond operator activity	126
4.15	eMOST die-bond operator M2M values	127
4.16	Die-bond operator utilisation	129
4.17	Summary result of wire-bond operator activity	130
4.18	eMOST wire-bond operator M2M values	131
4.19	Wire-bond operator utilisation	132
4.20	Set up new lot activities	133
4.21	Post lot tasks activities	134
4.22	Summary result of mold operator activity	136
4.23	eMOST mold operator M2M values	137
4.24	Error in Microsoft Excel mold M2M value	138
4.25	Mold operator utilisation	139
4.26	Summary result of final test operator activity	140

4.27	eMOST final test operator M2M values	141
4.28	Microsoft Excel final test M2M values	142
4.29	Final test operator utilisation	142
4.30	Top three contributors to final test operator utilisation	143
4.31	Production capacity analysis	145
4.32	Illustrative depiction of the simulation production system	147
4.33	Simulation base model result	151
5.1	Human loss category by process	168

## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Most index table	210
B	International labour organisation (ILO) standard allowance	211
C1	Wafer saw eMOST data	212
C2	Die-bond eMOST data	216
C3	Wire-bond eMOST data	221
C4	Mold eMOST data	223
C5	Final test eMOST data	229
D	Product demand and ratio information	239
E	Product information by process	242

## LIST OF ABBREVIATIONS

CCL	-	competency class level
CIMOSA	-	open system architecture for computer integrated manufacturing
CM	-	cellular manufacturing
DES	-	discrete event simulation
DHM	-	digital human model
EM	-	enterprise modelling
ES	-	expert system
ESPE-IP	-	bottleneck-centered simulation of personnel structure (German abbreviation)
JIT	-	just in time
GT	-	group technology
HSM	-	human system model
HTML	-	hypertext markup language
IE	-	industrial engineer
ILO	-	international labour organisation
MNC	-	multi-national company
MOST	-	Maynard operational sequence technique
MSI	-	manufacturing system institute
MTA	-	method and time analysis

M2M	-	man-to-machine model
MTS	-	method and time analysis
OEE	-	overall equipment efficiency
PDF	-	personal, fatigue and delay
PTS	-	predetermined time standard
SAT	-	semiconductor assembly and test
SDLC	-	system development life cycle
SM	-	simulation modelling
SOP	-	standard operating procedure
TMU	-	time management unit
TOC	-	theory of constraints
TPS	-	Toyota production system
TQM	-	total quality management
UPH	-	units per-hour
WIP	-	work in progress

## LIST OF PUBLICATIONS

### JOURNALS

1. Abdullah, R., Abd. Hashim, H., Abd. Rahman, M. N., and Salleh, M.R., 2016. Development of Enterprise Human System Modelling Framework in Support of Cellular Manufacturing Lean Operation. *Jurnal Teknologi*. In Press.
2. Abdullah, R., Abd. Rahman, M. N., and Khalil, S. N., 2015. Human System Modelling Technique for Semiconductor Assembly and Test. *Journal of Applied Mechanics and Material*. 761. pp. 624-628.
3. Abdullah, R., and Abd. Rahman, M. N., 2014. Work Study Architecture for Lean Waste Analysis to Achieve Optimum Man-Machine Configuration. *International Journal of Basic & Applied Science*. 14(1). pp.1-6.
4. Abdullah, R., Abd. Rahman, M. N., and Khalil, S. N., 2014. Human System Modelling for Optimum Labour Utilisation and Man-Machine Configuration. *International Journal of Engineering & Technology*. 14(1). pp.75-79.
5. Abdullah, R., Abd. Rahman, M. N., Halim, I., Omar, N., and Yusuf, Y., 2014. Lean Six Sigma Approach for Labour Productivity Improvement at Final Test Semiconductor Manufacturing. *Science International*. 26(5). pp.1817-1820.

## PROCEEDINGS

1. Abdullah, R., Abd. Hashim, H., Abd. Rahman, M. N., and Salleh, M.R., 2016. Development of Enterprise Human System Modelling Framework in Support of Cellular Manufacturing Lean Operation. *International Conference on Design and Concurrent Engineering (IDECON 2016)*. Langkawi, Malaysia, 19-20 September 2016. UTeM Publisher. In Press.
2. Abdullah, R., Omar, N., and Kamat, S. R., 2013. Work Study for Overall Process Efficiency at Manufacturing Company. *International Conference on Engineering Education (ICEE 2013)*. Madinah, Saudi Arabia, 22-25 December 2013. Federation of Engineering Institutions of Islamic Countries (FEIIC) Publisher.
3. Abd.Rahman, M. N., Abdullah, R., and Kamarudin, N., 2012. Work Study Techniques Evaluation At Back-End Semiconductor Manufacturing. *International Conference on Design and Concurrent Engineering (IDECON 2012)*. Melaka, Malaysia. 15-16 October 2012. UTeM Publisher.
4. Omar, M. K., Abdullah, R., and Abd Rahman, M. N., 2012. An Integrated Architecture for Lean Waste Analysis. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2012)*. Hong Kong, 10-13 December 2012. IEEE Publisher.
5. Omar, M. K., Abdullah, R., and Abd Rahman, M. N., 2012. Process and Labour Utilisation in the Electronic Industry: A Simulation Approach. *IEEE International Conference on Management of Innovation & Technology (ICMIT 2012)*. Sanur, Bali, Indonesia, 11-13 June 2012. IEEE Publisher.

# CHAPTER 1

## INTRODUCTION

Chapter 1 explains the background information and the thesis organisation which aims to disclose the originality of this study. Descriptive information is given in the study: background, problem statement, objectives, significance, scope, limitations and thesis structure.

### 1.1 Background

Manufacturing companies strive to meet customer requirement in order to stay competitive in the global market. Listening to the ‘voice-of-the-customers’ has been the key focus in which companies sought to capture inputs from the customers or better known as gathering customer requirements. In a study of 270 businesses, Ulwick (2002) summarised the customer requirements into solution, specification, need, and benefits. The author further explained that this means providing a solution to the customers with the products they need based on the design specifications that consider aspects such as size, weight, colour, and shape to achieve their specific needs (durable, dependable, and strong) and benefits (long lasting and low cost).

The motivation to conduct this research originates from the author’s twelve years working experience leading one of the multinational Company’s (MNC) Industrial Engineering Department. Among the major project conducted was the manufacturing manpower productivity improvement due to the increase in manufacturing system complexity and continuous effort to pursue a reduction in cost and cycle time without

affecting product quality and production agility. Various aspects contributed to the increase in manufacturing complexity such as high demand fluctuation, high product customization, globalised market demand, stiff cost competitiveness and shorter lead time expectation (Efthymiou et al., 2012). Therefore, the importance to measure the manufacturing complexity is crucial to better comprehend and control the various resources to achieve more efficient production systems (Efthymiou et al., 2014; Hon, 2005).

Over the years, the complex manufacturing issues were tackled through the introduction of various philosophies and methodologies. The Cellular Manufacturing (CM) is an example of a method being used to manage manufacturing complexity. The CM or also known as Group Technology (GT) was introduced based on the concept of clustering different types of equipment to process parts which have similar requirements (Canel et al., 2005; Huber and Hyer, 1985). This is contrary to the traditional type of job shop or batch manufacturing where identical equipment are grouped together resulting in high set-up frequency, reducing capacity and increasing queuing delays (Kannan and Ghosh, 1996).

There has been an increase in CM complexity due to the ever-changing environment and systems variations (Zhang, 2011). Moreover, the organisational structure which mainly comprises of human resources, equipment, material, and procedures will always need to be flexible for reconfiguration in the attempt to address the rapid changes in customer requirement. This is imperative to facilitate the need to meet customer delivery commitment timely and efficiently within all the related engineering and infrastructural support activities (Pandya et al., 1997).

The performance of the CM is determined by the two main components; human and machine or also known as the dual resource constraints (Cesani and Steudel, 2005). Norman et al. (2002) included process and material in addition to human and equipment to

be the major considerations in optimising manufacturing performance. Human competencies are valued as intangible assets of all businesses and are required for nearly all operational activities that affect the manufacturing performance (Morey et al., 2001). Human is also the most flexible component compared to other manufacturing resources (Ajaefobi et al., 2010). Unfortunately, most literature focused is on the equipment and technological aspects thus, undervaluing the importance of human on the production system performance (Digiesi et al., 2009). Since the human element is the most difficult component to be measured (Allender, 2000), there arises the need to model human performance and its effect on the system design, performance, and cost. This author emphasised on the modelling human in the early stage of the design in order to evaluate the effectiveness of the system in terms of the performance and cost.

The success of a manufacturing system modelled at the early stage of the design can tremendously improve with the consideration of human aspects which were typically oversimplified previously. Baines and Kay (2002) stated that the capability of the manufacturing system models is greatly appreciated with the inclusion of human factors much earlier in the system. Thus, this research is set to answer the issue of designing a human system model that can be used in the cellular manufacturing environment to study human performance and to integrate human aspects together with equipment and material to in managing the CM complexity.

## **1.2 Problem statement**

Many studies have been conducted in the area of modelling and simulation focusing on the equipment and process in tackling the issues of the cellular manufacturing complexity. However, one of the greatest challenges in manufacturing is the human factor since the roles human plays are often complex and interdependent. Human resource