



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF AN INNOVATIVE NEURO-FUZZY ASSESSMENT  
SYSTEM FOR THE EUROPEAN FOUNDATION FOR QUALITY  
MANAGEMENT**

**JAVAD DODANGEH**

**FK 2013 12**

**DEVELOPMENT OF AN INNOVATIVE NEURO-FUZZY ASSESSMENT  
SYSTEM FOR THE EUROPEAN FOUNDATION FOR QUALITY  
MANAGEMENT**

**By**

**JAVAD DODANGEH**

**This Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfillment of the Requirement for the Degree of Doctor of Philosophy**

**February 2013**

## DEDICATION

**I dedicate this thesis to the memory of my grandfather, Younesali Dodangeh, who passed away in June 2007. He played a vital role in my successions and studies.**

**And to my parents whose love and encouragement are the most wonderful of the many blessings that god has granted me.**

**Finally, this thesis is dedicated to all those who believe in the richness of learning.**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for degree of Doctor of Philosophy

**DEVELOPMENT OF AN INNOVATIVE NEURO-FUZZY ASSESSMENT  
SYSTEM FOR THE EUROPEAN FOUNDATION FOR QUALITY  
MANAGEMENT**

By

**JAVAD DODANGEH**

**February 2013**

**Chairman: Professor Rosnah bt. Mohd. Yusuff, PhD**

**Faculty: Engineering**

In growingly competitive business environment, numerous organizations adopt the total quality management (TQM) approach to achieve business excellence. To monitor the progress towards business excellence, thousands of organizations across the world use self-assessment on a regular basis. The European Foundation for Quality Management (EFQM) is among the most popular ones. However, the current self-assessment methods in EFQM model have some drawbacks and problems. Critical review of self-assessment models from literature showed that the majority of the assessment and self-assessment models developed were ambiguous, assumed assessment is only limited to certain and precise data and inability to consider the empirical investigation and expert knowledge in scoring and lack of a non-linear methodology for assessment system. Besides, none of the examined models developed consider simultaneous knowledge and experience of experts and historical behavior of variables.

Therefore, this research aims to develop a comprehensive intelligent assessment system using Neuro-Fuzzy system (Hybrid System) to overcome the uncertainties and complexities in the EFQM model and design fuzzy decision making model for best selection and ranking of Area for Improvement (AFI) in EFQM model.

A new assessment system based on Neuro-fuzzy is introduced and developed incrementally to address the deficiency in the existing models. Three different models have been introduced in this work: The first model is an assessment system based on the fuzzy inference system (FIS) in EFQM business excellence framework under conditions of imprecise (uncertain) data and nonlinear relations. The second model considers simultaneous knowledge and experience of experts and historical behavior of variables in EFQM and this model is a hybrid assessment system (Neuro-Fuzzy) which includes fuzzy inference system and adaptive neuro-fuzzy inference system (ANFIS). The third model is based on fuzzy multi criteria decision making (FMCDM) for selecting AFI in EFQM.

The models were tested and verified under real condition and were implemented in Rahyab Rayaneh Alborz Company. The case had been assessed by assessors and experts of an EFQM business excellence organization and internal assessors of the companies. Then the models were analyzed using the MATLAB software. Also by comparison of classic and new model, assessors and experts agreed with outputs of the developed (new) models.

The contribution of this research is modeling a new comprehensive assessment system in EFQM considering simultaneous knowledge and experience of experts and historical

behavior of variables (EFQM Criteria) using ANFIS. Moreover, organizational assessment and extraction of final Score for EFQM model under conditions of imprecise (uncertain) data and in nonlinear relations using FIS and employing FMCDM for priority of AFI in EFQM model would be considered as contributions for this study. The performances of the innovative assessment system proposed in this research include 1) considering the relation between variables as a nonlinear function, 2) ability to be implemented for any number of inputs and outputs, 3) providing more informative and reliable analytical results, 4) facilitating rapid assessment and decision making for managers, experts and assessors of organizations, 5) improving the FIS model efficiency by considering historical data and knowledge and experiences of experts through using hybrid assessment system (ANFIS), 6) being valid based on the hybrid system (ANFIS), due to the mean error between assessment of assessors and the output of model which was 0.000981517, 7) using FMCDM model for ranking and selecting AFIs in EFQM in practice and 8) being verified under real conditions and implemented in Rahyab Rayaneh Alborz Co. By comparison of classic and new model, assessors and experts agreed with the outputs of the developed (new) models.

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

**PEMBANGUNAN NEURO-SAMAR INOVATIF SISTEM PENILAIAN UNTUK YAYASAN EROPAH UNTUK PENGURUSAN KUALITI**

Oleh

**JAVAD DODANGEH**

**Februari 2013**

**Pengerusi: Professor Rosnah bt. Mohd. Yusuff, PhD**

**Fakulti: Kejuruteraan**

Dalam persekitaran perniagaan yang semakin berdaya saing, pelbagai organisasi mengguna pakai pendekatan pengurusan kualiti menyeluruh (TQM) untuk mencapai kecemerlangan perniagaan. Bagi memantau kemajuan ke arah kecemerlangan perniagaan, beribu-ribu organisasi di seluruh dunia menggunakan penilaian sendiri secara berkala. Yayasan Eropah bagi Pengurusan Kualiti (EFQM) adalah antara yang paling popular. Walau bagaimanapun, kaedah semasa penilaian sendiri dalam model EFQM mempunyai beberapa kelemahan dan masalah. Kajian semula kritikal model penilaian sendiri dari kesusasteraan menunjukkan bahawa majoriti model taksiran dan penilaian sendiri yang dibangunkan adalah kabur. Penilaian dianggap hanya terhad dan tepat kepada data tertentu dan ketidakupayaan untuk mempertimbang penyiasatan empirik dan pengetahuan pakar dalam pemarkahan disamping kekurangan mempunyai metodologi bukan linear untuk sistem penilaian. Selain itu, tiada model yang dikaji

mengambil kira pengetahuan dan pengalaman serentak dari pakar dan tingkah laku sejarah pembolehubah.

Oleh itu, kajian ini telah membangunkan satu penilaian komprehensif pintar yang menggunakan sistem Fuzzy Neuro (Sistem Hybrid) untuk mengatasi ketidakpastian dan kerumitan dalam model EFQM dan juga me reka bentuk model membuat keputusan kabur untuk pemilihan terbaik dan kedudukan Kawasan untuk Penambahbaikan (AFI) dalam model EFQM.

Sistem penilaian baru yang berdasarkan Neuro kabur diperkenalkan dan dibangunkan secara berperingkat untuk menangani kekurangan pada model yang sedia ada. Tiga model yang berbeza telah diperkenalkan dalam kajian ini: Model pertama ialah satu sistem penilaian yang berdasarkan sistem inferens logik kabur (FIS) di rangka kerja kecemerlangan perniagaan di EFQM bawah syarat-syarat data (pasti) tidak tepat dan hubungan tak linear. Model kedua menganggap pengetahuan dan pengalaman serentak pakar dan tingkah laku sejarah pembolehubah dalam EFQM di mana model ini adalah satu sistem penilaian hibrid (Fuzzy Neuro) yang termasuk dalam sistem inferens kabur dan penyesuaian neuro-kabur sistem inferens (ANFIS). Model ketiga adalah berdasarkan kabur kriteria membuat keputusan berbilang (FMCDM) untuk memilih AFI dalam EFQM.

Model telah dan disahkan di bawah keadaan sebenar dan telah dilaksanakan di sebuah syarikat pengeluar kereta mega serta syarikat elektrik serantau. Kes-kes ini telah dinilai oleh penilai dan pakar-pakar perniagaan organisasi EFQM kecemerlangan dan penilai dalaman syarikat. Kemudian model dianalisis dengan menggunakan perisian



MATLAB. Selain itu perbandingan model yang klasik dan baru, penilai dan pakar-pakar yang bersetuju dengan output model yang baru.

Sumbangan penyelidikan ini memodelkan sistem penilaian baru yang komprehensif di EFQM mengingati pengetahuan serentak dan pengalaman pakar dan tingkah laku sejarah pembolehubah (Kriteria EFQM) ANFIS menggunakan. Selain itu, penilaian organisasi dan pengekstrakan Skor akhir untuk model EFQM bawah keadaan data (tidak pasti) tidak tepat dan dalam hubungan tak linear menggunakan FIS dan FMCDM menggunakan untuk keutamaan tumbuh dalam model EFQM akan dipertimbangkan sebagai sumbangan untuk kajian ini. Prestasi sistem penilaian inovatif yang dicadangkan dalam kajian ini termasuk 1) mempertimbangkan hubungan antara pembolehubah sebagai fungsi linear, 2) keupayaan untuk dilaksanakan bagi apa-apa bilangan input dan output, 3) memberikan hasil yang lebih bermaklumat dan boleh dipercayai analitikal, 4) memudahkan penilaian pantas dan membuat keputusan untuk pengurus, pakar-pakar dan penilai organisasi, 5) meningkatkan kecekapan model FIS dengan mempertimbangkan data sejarah dan pengetahuan dan pengalaman pakar melalui menggunakan sistem taksiran hibrid (ANFIS), 6) menjadi sah berdasarkan sistem hibrid(ANFIS), disebabkan kesilapan min antara penilaian penilai dan output model yang 0,000981517, 7) menggunakan model FMCDM untuk kedudukan dan memilih AFIs dalam EFQM dalam amalan dan 8) yang disahkan di bawah syarat-syarat yang sebenar dan dilaksanakan di Rahyab Rayaneh Alborz Co. Mengikuti perbandingan model klasik dan baru, penaksir dan pakar-pakar bersetuju dengan output model (baru) maju.

## ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my supervisor Professor Dr. Rosnah bt. Mohd. Yusuff for her constant help and guidance. She has been helping me out and supported me throughout the course of this work and on several occasions. I am also extremely grateful to my thesis committee members Professor Dr.Napsiah bt. Ismail, Professor Dr. Mohd. Yusof Ismail, Dr.Mohammad Reza Beik Zadeh and Associate Professor Dr. Javad Jassbi for their attention, cooperation, comments and constructive criticism. Acknowledgment is due to the Director of Research Management Centre of UPM for granting financial support for this research.

I would like to express my sincere gratitude to the memory of my grandfather, Younesali Dodangeh, who encouraged and supported me for education until postgraduate studies, without his encouragement I could not have been achieve successful.

I would like to express my sincere thanks to Dr.Morteza Mousakhani as a president of QIAU, Dr.Vahid Nasehifar and Mohammad Reza Mosadegh as a managing director of Selseleyeh Hamgam Company for their support and encouragement.

I would like to express my sincere thanks to Mr.Farzad Ahmadzadeh managing director of Rahyab Rayaneh Alborz Company and assessors of the Company; I really appreciate their support and assistance during data collection of this study.

Finally, for those people who are not listed above but have given me a hand or advice, I would also like to say a word of thanks for their support.

I certify that a Thesis Examination Committee has met on 22th February 2013 to conduct the final examination of Javad Dodangeh on his thesis entitled “Development of an Innovative Neuro-Fuzzy Assessment System for the European Foundation for Quality Management” in accordance with the Universities and University Colleges Act 1971 and the constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of Thesis Examination Committee were as follows:

**Mohd Sapuan Salit, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Khairol Anuar Mohd Ariffin, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Tang Sai Hong, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Mohammed Saleem J Hashmi, PhD**

Professor  
School of Mechanical and Manufacturing Engineering  
Dublin City University  
(External Examiner)

---

**SEOW HENG FONG, PhD**

Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Rosnah bt. Mohd. Yusuff, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Napsiah bt Ismail, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Mohd Yusof Ismail, PhD**

Professor  
School of Manufacturing  
University Malaysia Perlis  
(Member)

**Mohammad Reza Beikzadeh, PhD**

Senior Staff Researcher  
Artificial Intelligence Center  
MIMOS Berhad  
(Member)

---

**BUJANG BIN KIM HUAT, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations, 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.

---

**JAVAD DODANGEH**

Date: 22 February 2013

# TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	vi
<b>ACKNOWLEDGEMENTS</b>	ix
<b>APPROVAL</b>	xi
<b>DECLARATION</b>	xii
<b>TABLE OF CONTENTS</b>	xiii
<b>LIST OF TABLES</b>	xvii
<b>LIST OF FIGURES</b>	xix
<b>LIST OF ABBREVIATIONS</b>	xxii
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	1
1.1 Introduction	1
1.2 Background of the Study	1
1.3 Problem Statement	4
1.4 Objectives of the Study	5
1.5 Scope of Study	6
1.6 Contribution of the Research	7
1.7 Structure of Thesis	9
<b>2 LITERATURE REVIEW</b>	10
2.1 Introduction	10
2.2 Total Quality Management	11
2.2.1 TQM Definition	12
2.2.2 Maturity Levels of TQM	14
2.2.3 Total Quality Management Frameworks	17
2.3 Business Excellence Frameworks	22
2.3.1 Fundamental Concepts of Excellence	24
2.3.2 The Malcolm Baldrige National Quality Award (MBNQA)	27
2.3.3 The Deming Prize	30
2.3.4 ISO 9000 Standards	32
2.3.5 European Foundation for Quality Management (EFQM)	33
2.3.5.1 The Eight Basic Concepts	34
2.3.5.2 The EFQM Excellence Model	36

2.4	Assessment System	45
2.4.1	Advantages of Self-Assessment	47
2.4.2	Self-Assessment Process	48
2.4.2.1	Defining Objectives and Scope	50
2.4.2.2	Choosing the Framework	50
2.4.2.3	Forming the Assessment Team	51
2.4.2.4	Collecting the Information	52
2.4.2.5	Assessment and Scoring	53
2.4.2.6	Consensus	54
2.4.2.7	The Site-Visit	57
2.4.2.8	Feedback	58
2.4.2.9	Action Planning	59
2.4.3	Self-Assessment Approaches in EFQM	60
2.4.3.1	Sub-Criteria Definition and Weighting in EFQM	61
2.4.3.2	An Overview of the Various Methods of Self-Assessment in EFQM	63
2.4.3.2.1	Questionnaire Method	64
2.4.3.2.2	Matrix Chart Method	66
2.4.3.2.3	Workshop Method	68
2.4.3.2.4	Pro-Forma Method	70
2.4.3.2.5	Award Simulation Method	71
2.4.4	Assessment Approaches	73
2.5	Artificial Intelligence (AI)	78
2.5.1	Expert Systems	79
2.5.2	Fuzzy Logic	81
2.5.2.1	Fuzzy Inference System (FIS)	82
2.5.2.2	Inference System Architecture	83
2.5.2.3	Fuzzy Multi Criteria Decision Making (FMCDM)	85
2.5.3	Artificial Neural Networks (ANN)	86
2.5.3.1	Adaptive Neuro Fuzzy Inference System (ANFIS)	88
2.6	Conclusion	92
<b>3</b>	<b>METHODOLOGY</b>	<b>93</b>
3.1	Introduction	93
3.2	Research Framework	93
3.3	Developing an Assessment Model using FIS in EFQM	96
3.3.1	Breaking Down EFQM Model (Hierarchy of EFQM Model)	98
3.3.2	Forming the Assessment Team	99
3.3.3	Conducting Assessment based on EFQM Assessment Form	99
3.3.4	Consensus	101
3.3.5	Modeling of FIS Assessment	101
3.3.5.1	Structure of FIS for Layer 3 (Sub-Criteria Layer)	104
3.3.5.2	Structure of FIS for Layer 2 (Criteria Layer)	106
3.3.5.3	Structure of FIS for Layer 1 (Area Layer)	107
3.3.5.4	Structure of FIS for Layer Zero (Final Score)	108

3.4 Designing an Assessment Model using Hybrid System (Neuro-Fuzzy) for in EFQM	109
3.4.1 Modeling of Adaptive Neuro-Fuzzy Inference System Assessment	111
3.4.1.1 Layer 1(Fuzzification Layer)	114
3.4.1.2 Layer 2(Fuzzy Rule Layer)	115
3.4.1.3 Layer 3(Normalization Layer)	115
3.4.1.4 Layer 4(Deffuzification Layer)	115
3.4.1.5 Layer 5(Summation Layer)	116
3.4.1.6 Input / Output Variables	116
3.4.1.7 Rule Making	117
3.4.1.8 Training the ANFIS and Obtaining Score of Results Area	118
3.4.1.9 Aggregating Scores of Areas and Obtaining Final Score	118
3.5 Designing a Fuzzy Decision Making Model for Selecting of AFIs in EFQM	119
3.5.1 Conduct Assessment based on EFQM	121
3.5.2 Consensus for Determining AFIs	121
3.5.3 Establish Criteria and Form Decision Matrix	121
3.5.4 Modeling of FMCDM	123
3.5.5 AFI Selection	125
3.6 Model Validation	125
3.7 Conclusion	125
<b>4 RESULTS AND DISCUSSIONS</b>	127
4.1 Introduction	127
4.2 Model Development	127
4.3 Case Study for Validation	128
4.4 Developing an Assessment Model Using FIS in EFQM	130
4.4.1 Breaking Down in EFQM Business Excellence Model	132
4.4.2 Forming the Assessment Team	133
4.4.3 Conduct Assessment Based on EFQM Assessment Form and Consensus	133
4.4.4 Modeling of FIS Assessment	134
4.4.4.1 Structure of FIS for Layer 3 (Sub-Criteria Layer)	135
4.4.4.2 Structure of FIS for Layer 2 (Criteria Layer)	146
4.4.4.3 Structure of FIS for Layer 1 (Area Layer)	156
4.4.4.4 Structure of FIS for Layer Zero (Final Score)	161
4.4.5 Discussion	166
4.5 Developing an Assessment Model Using Hybrid System (Neuro-Fuzzy) in EFQM	168
4.5.1 Data Generation	168
4.5.2 Rule Making	168
4.5.3 Training the ANFIS and Obtaining Score of Results Area	169
4.5.4 Validation of the model	171
4.5.5 Obtaining Score of Result Area Based on ANFIS Model	171
4.5.6 Obtaining Final Score in EFQM Using FIS	172



4.5.7 Discussion	173
4.6 Designing a Fuzzy Decision Making Model for Selecting of AFIs in EFQM	174
4.6.1 Conduct Assessment based on EFQM	174
4.6.2 Consensus for Determining AFIs	175
4.6.3 Establish Criteria and Form Decision Matrix	175
4.6.4 Discussion	180
4.7 Conclusion	182
<b>5 CONCLUSIONS AND RECOMMENDATIONS</b>	<b>183</b>
5.1 Introduction	183
5.2 Summary and Conclusion	183
5.3 Limitations of the Study	185
5.3.1 Limitations Due to Lack of Appropriate Research Background	185
5.3.2 Interdisciplinary Limitations	186
5.4 Conclusion for Research Contribution	186
5.5 Recommendations for Future Research	187
<b>REFERENCES</b>	<b>188</b>
<b>APPENDICES</b>	<b>199</b>
<b>BIODATA OF STUDENT</b>	<b>218</b>
<b>LIST OF PUBLICATIONS</b>	<b>219</b>