

**OPTIMIZATION OF MULTI-AGENT
TRAFFIC NETWORK SYSTEM WITH
Q-LEARNING-TUNED FITNESS FUNCTION**

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UMS

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THE DEGREE OF DOCTOR OF PHILOSOPHY**

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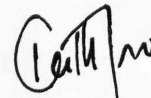
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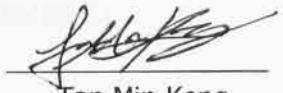
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I hereby declare that the material in this thesis is my own except for quotations, equations, summaries and references, which have been duly acknowledged.

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT

This study aims to explore the potential of implementing multi-agent-based Genetic Algorithm (GA) with interactive metamodel to acquire regular optimisation on dynamic characteristic of traffic flow. The idea is proposed in effort of accessing the functionality of the proposed algorithm to improve the smoothness of traffic flow in a network. As such, level-of-service of traffic network could be improved by optimising the utilisation of network capacity while minimising the travel delay and vehicles in queue. Traditionally, the common practice is to identify a fixed timing plan profile via offline and assumed it as a "nominal optimised" for the actual traffic flow. Whether the traffic signal is fully optimised under various traffic conditions, fluctuations in traffic demand and numerous uncertainties due to driver's driving behaviour remaining as a challenging topic. Scholars have proposed artificial intelligence (AI) to be integrated into the signal control system to improve the adaptiveness of the control system. However, the evaluation function used in the AI is developed based on historical traffic data. This offline predetermined evaluation function has limited the AI in exploring the stochastic and non-uniform traffic flow environment to search the optimum solution. Therefore, a notable fitness function with interactive metamodel for GA or known as improved GA is proposed. The dynamic environment causing the need of dynamic modelling for better dynamic optimisation will be catered via a specifically formulated interactive fitness function. The interactive metamodel is extracted using Q-Learning (QL) via online observing and learning of the outflow-inflow traffic characteristics. The improved GA is then embedded into the signal controller of every intersection or known as agent. Each agent has the autonomy in controlling their local intersection which are coordinated by a superior agent that has superiority in overwriting the local control decision if conflict occurs. The improved GA is tested using simulated grid traffic network model under various traffic scenarios. Results indicate the improved GA has improved 7.0 – 9.0 % in minimising the average delay as compared to the classical GA (without interactive metamodel).

ABSTRAK

OPTIMIZATION OF MULTI-AGENT TRAFFIC NETWORK SYSTEM WITH Q-LEARNING-TUNED FITNESS FUNCTION

Kajian ini bertujuan untuk menerokai potensi melaksanakan sistem multiagen yang berasas Algoritma Genetik (GA) dengan iteraktif metamodel bagi mengoptimumkan aliran trafik yang dinamik. Idea ini dicadangkan sebagai satu usaha untuk mengakses kebolehan algoritma yang dicadangkan bagi meningkatkan kelancaran aliran lalu lintas. Justeru, tahap perkhidmatan rangkaian trafik dapat ditingkatkan dengan mengoptimumkan penggunaan kapasiti rangkaian sambil meminimumkan kelewatan perjalanan dan bilangan kenderaan dalam barisan. Secara tradisional, profil pelan masa tetap akan dikenalpasti dan pelan ini akan dianggap sebagai "pengoptimuman nominal". Samaada isyarat lalu lintas dioptimum sepenuhnya di bawah pelbagai keadaan trafik, variasi dalam aliran trafik dan beberapa faktor ketidakpastian yang disebabkan oleh tingkah laku pemandu adalah kekal sebagai topik yang mencabar. Oleh itu, para penyelidik mencadangkan penggunaan kecerdasan buatan (AI) untuk meningkatkan keberkesanan sistem kawalan lampu isyarat. Walau bagaimanapun, fungsi penilaian yang digunakan dalam AI adalah dibangunkan berdasar data-data aliran trafik masa lalu. Justeru, fungsi evaluasi tersebut menghadkan AI dalam menerokai keadaan lingkungan aliran trafik yang stokastik dan tidak seragam untuk mencari penyelesaian optimum. Oleh itu, fungsi kecerdasan yang ketara dengan iteraktif metamodel untuk GA dicadangkan. Keadaan dinamik menyebabkan keperluan iteraktif metamodel untuk pengoptimuman dinamik yang lebih baik dapat dipenuhi melalui fungsi kecerdasan dinamik yang khusus dirumus. Model dinamik diekstrak dengan menggunakan Q-Learning (QL) melalui pemerhatian dan mempelajari ciri-ciri aliran trafik. Pendekatan yang dicadangkan itu kemudian dimasukkan ke dalam sistem kawalan bagi setiap persimpangan atau dikenali sebagai agen. Setiap agen mempunyai autonomi dalam pengawalan persimpangan masing-masing dan diselaraskan oleh satu agen penyelia yang mempunyai keunggulan dalam menggantikan keputusan kawalan jika konflik berlaku. Keputusan menunjukkan GA yang dicadangkan mampu meningkatkan prestasi 7.0 – 9.0 % berbanding dengan klasik GA (tanpa iteraktif metamodel).

TABLE OF CONTENTS

	Page
TITLE	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
<i>ABSTRAK</i>	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	xii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xxi
LIST OF NOMENCLATURES	xxv
LIST OF APPENDICES	xxxii
LIST OF GLOSSARIES	xxxiii

CHAPTER 1: INTRODUCTION	1
1.1 Research Background	2
1.2 Overview of Traffic Network Control	4
1.2.1 Background of Traffic Network	4
1.2.2 Background of Adaptive Signal Controls	6
1.3 Research Motivation	9
1.3.1 Problem Statement	10
1.3.2 Challenges	11
1.4 Research Aim	12
1.4.1 Objectives	12
1.4.2 Scope of Work	14
1.5 Thesis Outline	15
CHAPTER 2: REVIEW OF SIGNAL OPTIMISATION	17
2.1 Traffic Signal Optimisation	18
2.2 Traffic Network Models	20
2.2.1 Microscopic Model	21
2.2.2 Macroscopic Model	23
2.2.3 Mesoscopic Model	25
2.3 Evolutionary-based Signal Optimisers	27
2.3.1 Evolutionary-based Algorithms	28
2.3.2 Fitness Evaluation Functions	34
2.3.3 Metamodels of Fitness Function	36
2.4 Network Control Architectures	38
2.4.1 Centralised Architecture	39
2.4.2 Decentralised Architecture	41
2.4.3 Hierarchical Architecture	43
2.5 Summary for Traffic Signal Optimisation	45

CHAPTER 3: METHODOLOGY OF SIGNAL OPTIMISATION	47
3.1 Research Framework	48
3.2 Design of Benchmarked Traffic Network Model	50
3.2.1 Grid Network Topology	52
3.2.2 Traffic Flow Model	54
3.2.3 Traffic Signal Model	56
3.3 Design of Interactive Traffic Signal Optimiser	58
3.3.1 Q-Learning-based Fitness Metamodel	60
3.3.2 Genetic Algorithm-based Signal Optimiser	63
3.3.3 Hybrid of Q-Learning and Genetic Algorithm	65
3.4 Design of Multi-Agent Traffic Optimisation System	67
3.4.1 Decentralised System	69
3.4.2 Hierarchical System	71
3.4.3 Performance Metric	73
3.5 Summary for Research Framework	75
CHAPTER 4: MODELLING OF TRAFFIC NETWORK	77
4.1 Network Modelling	78
4.2 Mathematical Modelling of Simulated Grid Model	80
4.2.1 Grid Network Modelling	81
4.2.2 Arrival Traffic Modelling	84
4.2.3 Departure Traffic Modelling	86
4.3 Interactive Metamodeling of Simulated Grid Model	88
4.3.1 Development of Q-Learning-based Extractor	89
4.3.2 Non-Uniform Traffic Flow Characteristics	92
4.3.3 Performance of Q-Learning-based Extractor	95
4.4 Control Characteristics of Simulated Grid Model	97
4.4.1 Development of Conventional Signal Controller	98
4.4.2 Performance of Conventional Signal Controller	101
4.4.3 Performance Assessment of Conventional Signal Controller	103
4.5 Summary for Network Modelling	105

CHAPTER 5: COMPUTATION OF EVOLUTIONARY OPTIMISERS	107
5.1 Evolutionary Optimisers	108
5.2 Genetic Algorithm based Decentralised Signal Optimiser	110
5.2.1 Genetic Algorithm with Adaptive Fitness Evaluations	111
5.2.2 Genetic Algorithm with Adaptive Parameter Settings	116
5.2.3 Performance Assessment of Genetic Algorithm	126
5.3 Swarm Optimisation based Decentralised Signal Optimiser	128
5.3.1 Swarm Optimisation with Adaptive Fitness Evaluations	129
5.3.2 Swarm Optimisation with Adaptive Parameter Settings	134
5.3.3 Performance Assessment of Swarm Optimisation	144
5.4 Differential Evolution based Decentralised Signal Optimiser	146
5.4.1 Differential Evolution with Adaptive Fitness Evaluations	147
5.4.2 Differential Evolution with Adaptive Parameter Settings	152
5.4.3 Performance Assessment of Differential Evolution	162
5.5 Summary for Evolutionary Optimisers	165
CHAPTER 6: ANALYSIS OF PERFORMANCE OPTIMISATION	167
6.1 Performance Analysis	168
6.2 Hierarchical-based Multi-Agent Optimisation System	170
6.2.1 Hybrid of Centralised and Decentralised Systems	171
6.2.2 Exploration and Exploitation Agents	173
6.2.3 Dynamic Fitness Mechanism	175
6.3 Genetic Algorithm in Various Control Architectures	176
6.3.1 Centralised Genetic Algorithm-based Signal Optimiser	177
6.3.2 Hierarchical Genetic Algorithm-based Signal Optimiser	186
6.3.3 Performance Evaluation of Various Control Architectures	197
6.4 Practicability of Programmable Signal Optimiser	199
6.4.1 Programmable Interface Optimiser	200
6.4.2 Genetic Algorithm-based Programmable Optimiser	202
6.4.3 Performance Evaluation of Programmable Optimiser	207
6.5 Summary for Performance Analysis	209

CHAPTER 7: CONCLUSION	211
7.1 Summary	212
7.2 Research Findings	213
7.2.1 Utilising Interactive Metamodelling in Optimisation	214
7.2.2 Hybridising Centralised and Decentralised Systems	215
7.3 Research Contributions	216
7.3.1 Traffic Network Modelling	216
7.3.2 Genetic Algorithm with Interactive Metamodel	217
7.4 Recommendation	218
7.4.1 Future Research Development	219
7.4.2 Potential Industrial Application	219
7.5 Concluding Remarks	220
 REFERENCES	 221
 APPENDICES	 241



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LIST OF TABLES

	Page
Table 2.1 : Review of Microscopic Traffic Flow Models	22
Table 2.2 : Review of Macroscopic Traffic Flow Models	24
Table 2.3 : Summary of Traffic Flow Model Review	26
Table 2.4 : Review of Evolutionary-based Traffic Signal Optimisers	33
Table 2.5 : Review of Fitness Functions for Traffic Signal Optimisation	35
Table 2.6 : Review of Metamodels of Fitness Function	37
Table 2.7 : Review of Signal Control Architecture	44
Table 2.8 : Summary of Platform Model and Signal Optimiser Reviews	46
Table 3.1 : Summary of Research Methodology	76
Table 4.1 : Description for Urban Arterial Road Design	83
Table 4.2 : Modelling Parameters of Grid Network Model	83
Table 4.3 : Pseudo-code of Generating Inflow Vehicles	85
Table 4.4 : Pseudo-code of Q-Learning-based Metamodelling	89
Table 4.5 : Parameters of Q-Learning-based Metamodelling	90
Table 4.6 : Status Criteria for Signalised Intersection	100
Table 4.7 : Traffic Demand for Nominal and Inflow Deviation Cases	101

Table 4.8 : Conventional Non-Adaptive Signal Controller Settings	101
Table 4.9 : Performance Measurement of Non-Adaptive Signal Controller	103
Table 4.10: Summary of Network Modelling	106
Table 5.1 : Pseudo-code of Genetic Algorithm-based Signal Optimiser	110
Table 5.2 : Performance Measurement of GA with Various Fitness Functions	111
Table 5.3 : Performance Measurement of GA with Adaptive Population	116
Table 5.4 : Performance Measurement of GA with Adaptive Reproduction	121
Table 5.5 : Performance Measurement of Decentralised GA Optimisers	126
Table 5.6 : Pseudo-code of Swarm Optimisation-based Signal Optimiser	128
Table 5.7 : Performance Measurement of SO with Various Fitness Functions	129
Table 5.8 : Performance Measurement of SO with Adaptive Population	134
Table 5.9 : Performance Measurement of SO with Adaptive Reproduction	139
Table 5.10: Performance Measurement of Decentralised SO Optimisers	144
Table 5.11: Pseudo-code of Differential Evolution-based Signal Optimiser	146
Table 5.12: Performance Measurement of DE with Various Fitness Functions	147
Table 5.13: Performance Measurement of DE with Adaptive Population	152
Table 5.14: Performance Measurement of DE with Adaptive Reproduction	157
Table 5.15: Performance Measurement of Decentralised DE Optimisers	162

Table 5.16: Summary of Computational Algorithm	166
Table 6.1 : Performance Measurement of Centralised Systems	177
Table 6.2 : Performance Measurement of Hierarchical System	186
Table 6.3 : Processing Specification of Microcontroller Computation	199
Table 6.4 : Performance Measurement of Programmable Optimiser	202
Table 6.5 : Summary of Hierarchical Optimisation Systems	209
Table B.1 : Processing Specification of Workstation Computation	243
Table C.1 : Level of Service for Signalised Intersection in Urban Area	244
Table D.1 : Parameters of Genetic Algorithm-based Signal Optimiser	245
Table D.2 : Parameters of Swam Optimisation-based Signal Optimiser	245
Table D.3 : Parameters of Differential Evolution-based Signal Optimiser	245

LIST OF FIGURES

	Page
Figure 1.1 : Strategies for relieving traffic congestion	5
Figure 1.2 : Adaptive traffic signal control systems	8
Figure 1.3 : Research gap identification map	10
Figure 2.1 : Breakdown of four-phase cycle at an intersection	19
Figure 2.2 : Types of traffic flow model	20
Figure 2.3 : Schematic diagram of car-following model	21
Figure 2.4 : Schematic diagram of cellular automaton model	22
Figure 2.5 : Types of evolutionary-based traffic signal optimiser	27
Figure 2.6 : Types of traffic signal control architecture	38
Figure 2.7 : Architecture of centralised control system	39
Figure 2.8 : Time-space diagram for centralised system	40
Figure 2.9 : Architecture of decentralised control system	41
Figure 2.10: Architecture of hierarchical control system	43
Figure 3.1 : Flowchart of research methodology	49
Figure 3.2 : Flowchart of platform model development	51
Figure 3.3 : Schematic diagram of grid traffic network	52

Figure 3.4 : Actual traffic signalised intersection in Kota Kinabalu, Malaysia	53
Figure 3.5 : Traffic signal distributions for a four-legged intersection	56
Figure 3.6 : Traffic phase patterns for a four-legged intersection	57
Figure 3.7 : Flowchart of adaptive signal controller development	59
Figure 3.8 : Flowchart of Q-Learning	60
Figure 3.9 : Metamodel of traffic network	61
Figure 3.10: Flowchart of Genetic Algorithm	64
Figure 3.11: Flowchart of interactive traffic signal optimiser development	66
Figure 3.12: Flowchart of multi-agent system development	68
Figure 3.13: Conceptual design of decentralised multi-agent system	70
Figure 3.14: Conceptual design of hierarchical multi-agent system	72
Figure 4.1 : Grid network platform model	80
Figure 4.2 : Relationships between geometric design elements	81
Figure 4.3 : Schematic diagram of Q-Learning-based metamodel extractor	88
Figure 4.4 : Parameter variations in traffic network	92
Figure 4.5 : Traffic flow characteristics	93
Figure 4.6 : Performance profile of QL-based interactive metamodel	95
Figure 4.7 : Schematic diagram of conventional traffic signal controller	97

Figure 4.8 : Performance profile of non-adaptive signal controller	102
Figure 5.1 : Schematic diagram decentralised GA signal optimiser	110
Figure 5.2 : Performance profile of GA_{AW-D} based decentralised system	112
Figure 5.3 : Performance profile of GA_{ED-D} based decentralised system	113
Figure 5.4 : Performance profile of GA_{IM-D} based decentralised system	114
Figure 5.5 : Performance profile of GA_{AW-AP} based decentralised system	117
Figure 5.6 : Performance profile of GA_{ED-AP} based decentralised system	118
Figure 5.7 : Performance profile of GA_{IM-AP} based decentralised system	119
Figure 5.8 : Performance profile of GA_{AW-AR} based decentralised system	122
Figure 5.9 : Performance profile of GA_{ED-AR} based decentralised system	123
Figure 5.10: Performance profile of GA_{IM-AR} based decentralised system	124
Figure 5.11: Model error of GA's explicit and interactive metamodels	127
Figure 5.12: Schematic diagram of decentralised SO signal optimiser	128
Figure 5.13: Performance profile of SO_{AW-D} based decentralised system	130
Figure 5.14: Performance profile of SO_{ED-D} based decentralised system	131
Figure 5.15: Performance profile of SO_{IM-D} based decentralised system	132
Figure 5.16: Performance profile of SO_{AW-AP} based decentralised system	135
Figure 5.17: Performance profile of SO_{ED-AP} based decentralised system	136

Figure 5.18 : Performance profile of SO_{IM-AP} based decentralised system	137
Figure 5.19 : Performance profile of SO_{AW-AR} based decentralised system	140
Figure 5.20 : Performance profile of SO_{ED-AR} based decentralised system	141
Figure 5.21 : Performance profile of SO_{IM-AR} based decentralised system	142
Figure 5.22 : Model error of SO's explicit and interactive metamodels	145
Figure 5.23 : Schematic diagram of decentralised DE signal optimiser	146
Figure 5.24 : Performance profile of DE_{AW-D} based decentralised system	148
Figure 5.25 : Performance profile of DE_{ED-D} based decentralised system	149
Figure 5.26 : Performance profile of DE_{IM-D} based decentralised system	150
Figure 5.27 : Performance profile of DE_{AW-AP} based decentralised system	153
Figure 5.28 : Performance profile of DE_{ED-AP} based decentralised system	154
Figure 5.29 : Performance profile of DE_{IM-AP} based decentralised system	155
Figure 5.30 : Performance profile of DE_{AW-AR} based decentralised system	158
Figure 5.31 : Performance profile of DE_{ED-AR} based decentralised system	159
Figure 5.32 : Performance profile of DE_{IM-AR} based decentralised system	160
Figure 5.33 : Model error of DE's explicit and interactive metamodels	163
Figure 6.1 : Schematic diagram of hierarchical-based multi-agent system	170
Figure 6.2 : Arbitration process of hierarchical optimisation system	172

Figure 6.3 : Exploitation and exploration in hierarchical system	174
Figure 6.4 : Performance profile of GA_{ED-C} under nominal condition	178
Figure 6.5 : Performance profile of GA_{ED-C} under saturated condition	179
Figure 6.6 : Performance profile of GA_{ED-C} under agent failure condition	180
Figure 6.7 : Performance profile of GA_{IM-C} under nominal condition	182
Figure 6.8 : Performance profile of GA_{IM-C} under saturated condition	183
Figure 6.9 : Performance profile of GA_{IM-C} under agent failure condition	184
Figure 6.10: Performance profile of GA_{ED-H} under nominal condition	187
Figure 6.11: Performance profile of GA_{ED-H} under agent failure condition	188
Figure 6.12: Performance profile of GA_{ED-H} under unwanted incident	189
Figure 6.13: Performance profile of GA_{ED-H} under oversaturated condition	190
Figure 6.14: Performance profile of GA_{IM-H} under nominal condition	192
Figure 6.15: Performance profile of GA_{IM-H} under agent failure condition	193
Figure 6.16: Performance profile of GA_{IM-H} under unwanted incident	194
Figure 6.17: Performance profile of GA_{IM-H} under oversaturated condition	195
Figure 6.18: Picture of the developed programmable optimiser	200
Figure 6.19: Schematic diagram of the developed programmable optimiser	201
Figure 6.20: Performance profile of GA_{PO} under nominal condition	203

Figure 6.21 : Performance profile of GA _{PO} under agent failure condition	204
Figure 6.22 : Performance profile of GA _{PO} under unwanted incident	205
Figure 6.23 : Performance profile of GA _{PO} under oversaturated condition	206



LIST OF ABBREVIATIONS

- AF** – Agent failure condition
- AI** – Artificial intelligence
- ANFIS** – Adaptive Neuro-Fuzzy Inference System
- ANN** – Artificial Neural Network
- CBD** – Central business district
- CDF** – Cumulative distribution function
- CO₂** – Carbon dioxide
- DE** – Differential Evolution
- DE_{AW-AP}** – DE_{AW-D} optimiser with adaptive population resizing
- DE_{AW-AR}** – DE_{AW-D} optimiser with adaptive reproduction mechanism
- DE_{AW-D}** – Decentralised Differential Evolution with average waiting
- DE_{ED-AP}** – DE_{ED-D} optimiser with adaptive population resizing
- DE_{ED-AR}** – DE_{ED-D} optimiser with adaptive reproduction mechanism
- DE_{ED-D}** – Decentralised Differential Evolution with estimated delay
- DE_{IM-AP}** – DE_{IM-D} optimiser with adaptive population resizing
- DE_{IM-AR}** – DE_{IM-D} optimiser with adaptive reproduction mechanism

- DE_{IM-D}** – Decentralised Differential Evolution with interactive metamodel
- DMAS** – Decentralised multi-agent system
- FL** – Fuzzy Logic
- GA** – Genetic Algorithm
- GA_{AW-AP}** – GA_{AW-D} optimiser with adaptive population resizing
- GA_{AW-AR}** – GA_{AW-D} optimiser with adaptive reproduction mechanism
- GA_{AW-D}** – Decentralised Genetic Algorithm with average waiting
- GA_{ED-AP}** – GA_{ED-D} optimiser with adaptive population resizing
- GA_{ED-AR}** – GA_{ED-D} optimiser with adaptive reproduction mechanism
- GA_{ED-C}** – Centralised Genetic Algorithm with estimated delay
- GA_{ED-D}** – Decentralised Genetic Algorithm with estimated delay
- GA_{ED-H}** – Hierarchical Genetic Algorithm with estimated delay
- GA_{IM-AP}** – GA_{IM-D} optimiser with adaptive population resizing
- GA_{IM-AR}** – GA_{IM-D} optimiser with adaptive reproduction mechanism
- GA_{IM-C}** – Centralised Genetic Algorithm with interactive metamodel
- GA_{IM-D}** – Decentralised Genetic Algorithm with interactive metamodel
- GA_{IM-H}** – Hierarchical Genetic Algorithm with interactive metamodel
- GA_{PO}** – Genetic Algorithm based programmable optimiser

- GDP** – Gross domestic product
- GPS** – Global positioning system
- HMAS** – Hierarchical multi-agent system
- IoT** – Internet of things
- JKR** – Public Works Department Malaysia
- LAN** – Local area network
- LT** – Left-turn
- LWR** – Lighthill-Whitham-Richards model
- NC** – Nominal condition
- OC** – Oversaturated condition
- PDF** – Probability density function
- QL** – Q-Learning
- ROW** – Right-of-way
- RT** – Right-turn
- SC** – Saturated condition
- SCOOT** – Split Cycle Offset Optimisation Technique
- SCATS** – Sydney Coordinated Adaptive Traffic System
- SO** – Swarm Optimisation